MILITARY SURGICAL MANUALS

NATIONAL RESEARCH COUNCIL

VOLUMES IN THIS SERIES

I Manual of Standard Practice of Plastic and Maxillo-facial Surgery
II Ophthalmology and Otolaryngology
III Abdominal and Genito-urinary Injuries
IV Orthopedic Subjects
V Burns, Shock, Wound Healing, and Vascular Injuries
VI Neurosurgery and Thoracic Surgery

FOREWORD

THE Medical Department of the Army has been confronted with the necessity for enormous and rapid expansion paralleling that of the armed forces. The state of war has greatly increased the task of furnishing adequate medical care for Army personnel since battle casualties are added to the already wide range of diseases and injuries that must be treated.

Expansion of the medical establishment of the Army is entirely dependent on entry into the service of individuals from civil life While most reserve officers have had a varying amount of military training, practically all medical officers will encounter problems in the military service entirely foreign to their previous experiences. These problems are by no means confined to those of an administrative nature many are distinctly professional. The military situation imposes certain restricting factors which render impracticable some procedures that would be considered ideal in civil life. The goal of furnishing the best possible treatment to all individuals is the same in the Army as in civil life, but the means to attain that goal may differ materially

There has been a marked tendency to specialization within the medical profession since the first World War This tendency is fundamentally sound but does serve to increase the problems of many individual medical officers in time of war Specialization cannot be followed to the same degree in the military service as in civil life While many highly qualified specialists in the various fields of medicine and surgery will serve in like capacities in the Army this cannot invariably be true The great burden of medical care will fall on medical officers outside the highly specialized fields. It is thus essential that nearly all medical officers be familiar with the principles of military surgery Recent advances in therapy have resulted in radical modification of certain principles of treatment that were formerly considered sound.

This series of texts presents in compact form essential up-to-date and reliable information regarding military surgery The various sections have been written by outstanding authorities in their respective fields. They have been prepared for publication under the auspices of the Division of Medical Sciences of the National Research Council.

These texts will prove a highly valuable source of professional information for any surgeon desiring a knowledge of the principles of military surgery Their application is not confined to military medicine, for most of the wounds and injuries of modern warfare may be duplicated in civil emergencies The condensed form and avoidance of debatable points will render them very convenient for quick reference as well as for more mature study

These volumes represent an important addition to the field of surgical texts The individuals instrumental in their preparation have made a distinct contribution to civil and military medicine by their assemblage and presentation of this timely professional information

JAMES C MAGEE
Major General, U S Army
The Surgeon General

The naval medical officer is often faced with medical or surgical situations with which he must deal entirely alone and without the opportunity for consultation and assistance from other members of his profession He may be the only medical man on a ship in the middle of an ocean, and any surgical emergency must be met by him and him alone He cannot refer the case to a specialist, he himself must do everything that is necessary It is important that he have the best assistance that professional books and journals can give him A volume such as this, which contains practical and essential things, readily accessible, is a real help to a medical officer and patient in this situation

ROSS T MCINTIRE
Rear Admiral, Medical Corps
Surgeon General, U S Navy

NEUROSURGERY AND THORACIC SURGERY

Prepared and Edited by the Subcommittees on Neurosurgery and Thoracic Surgery of the Committee on Surgery of the Division of Medical Sciences of the National Research Council

ILLUSTRATED

Philadelphia & London

W B SAUNDERS COMPANY

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INTRODUCTION

THIS volume is one of a series developed under the auspices of the Division of Medical Sciences of the National Research Council to furnish medical departments of the United States Army and Navy with compact presentations of necessary information in the field of military surgery The individual manuals are prepared under the auspices of the various subcommittees of the Committee on Surgery of the Division of Medical Sciences of the National Research Council and are edited by the Committee on Information.

The six volumes cover the following subjects plastic and maxillofacial surgery ophthalmology and otolaryngology abdominal and genito-urinary injuries, orthopedic subjects burns, shock, vascular injuries, and wound healing and neurosurgery and thoracic surgery

The Committee on Surgery includes Drs. Evarts A. Graham, Chairman, Irvin Abell, Donald C. Balfour George E. Bennett, Warren H. Cole, Frederick A. Coller Robert H. Ivy Herman L. Kretschmer Charles G Mixter Howard C. Naffziger Alton Ochsner I. S. Ravdin, and Allen O Whipple. The Committee on Information includes Drs. Morris Fishbein, Chairman, J J Bloomfield, John F Fulton, Richard M. Hewitt, Ira V Hiscock, Sanford V Larkey and Robert N Nye.

Most of the detail of the editorial work has been done by Dr Richard M. Hewitt, assisted by James Eckman, in the Division of Publications, the Mayo Clinic, Rochester Minnesota.

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CHARLES S. STEPHENSON *Captain U S Navy Medical Corps Navy Department Representative National Research Council*

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Prepared and Edited by the Subcommittee on Neurosurgery of the Committee on Surgery of the Division of Medical Sciences of the National Research Council

HOWARD C NAFFZIGER, *Chairman*

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PREFACE

THE purpose of this manual is to supply to those who already have had at least some experience in civil neurosurgery certain particulars regarding established methods of treatment in the rather special field of gunshot and shell wounds of the brain, spinal cord, and peripheral nerves, as seen in modern warfare. In addition to material on these special wounds, the ordinary types of head and spinal injuries are considered, since these may be just as frequent in modern warfare as wounds from missiles. Finally, a chapter on the infectious complications of skull and spinal injuries is given, but no attempt has been made to cover the late sequelae, such as convulsions and various post traumatic states, since patients needing treatment for these conditions eventually will be referred to permanent hospitals suited to these purposes.

The information contained herein has been gathered from a variety of sources. Much has been supplied by those who had an abundant experience in the war of 1914–1918 The literature of war wounds from that world conflict and from the present one has been reviewed. Special help has been obtained from the British manual published in 1918 by the Royal Army Medical Corps, from the *Military Medical Manual* containing the views of the French school, and from the directions issued by Dr Harvey Cushing to the American neurosurgical teams in the war of 1914–1918 Certain observations made experimentally have been taken into consideration, and some of the applications of advances in neurosurgery have been advocated. We are particularly indebted to Professor Hugh Cairns, Oxford, England, and to Professor Geoffrey Jefferson, Manchester England, for personal communications regarding methods current in the present war

Much of the subject matter in the chapter on infections of the nervous system has been taken verbatim from the article by Dr Francis C. Grant in *Injuries of the Skull Brain and Spinal Cord* by kind consent of the editor Dr Samuel Brock, and the publishers, the Williams and Wilkins Company to whom grateful acknowledgment is made. Finally we are greatly indebted to Thomas Nelson and Sons and to Paul B. Hoeber Inc., for permission to use material from the articles of Dr Byron Stookey and Drs. Pollock and Davis, respec

tively, in the chapter entitled "Injuries of Peripheral Nerves," and to Cunningham's *Textbook of Anatomy*, published by William Wood and Company, to Werner Spalteholz's *Hand-Atlas of Human Anatomy*, published by J B Lippincott Company, and to the *Manual of Neurosurgery*, published by the Surgeon General's office, for the use of illustrations in the chapter dealing with peripheral nerves

The material to be considered has been grouped in five main categories (1) gunshot and other injuries of the scalp, skull and brain, (2) gunshot and other injuries of the spinal cord, (3) injuries of the intervertebral disks in military service, (4) injuries of the peripheral nerves, and (5) infections of the nervous system and its coverings arising from injuries of war It is our object to set forth what we believe would be the ideal treatment for these special injuries from the time of their infliction until the patient is able to be discharged from a hospital in the zone of the interior

The present manual will form, it is hoped, a working basis which can be added to or modified in any way, as information accrues or circumstances warrant

Finally, it must be remembered by all those concerned with handling the wounded in warfare that it is their prime object to do everything for the greatest good of the greatest number, and thus to return the highest percentage of men to active duty In times of great stress patients must be selected for operation on this basis, but it must be borne in mind always that it is better and more satisfactory to do complete and careful operations, even if fewer of them can be done, than to do a large number of incomplete operations, since the complications and end-results of the latter are far worse than those arising from complete operations

SUBCOMMITTEE ON NEUROSURGERY

Committee on Surgery
Division of Medical Sciences
National Research Council

CONTENTS

1

NEUROSURGERY

CHAPTER I

GUNSHOT AND OTHER INJURIES OF SCALP, SKULL, AND BRAIN

GILBERT HORRAX, M.D. and CLAUDE C. COLEMAN, M.D.

THIS chapter has been written in two divisions by different authors working independently The first division deals with gunshot and shell wounds, many of which are of the so-called penetrating type. Herein, by a "penetrating wound" is meant one in which the continuity of the dura, and perhaps of other meninges, is interrupted by any means whatever The second division of the chapter deals with wounds of the head caused otherwise than by shot and shell that is, head injuries similar to those commonly seen in civil life, such as those resulting from falls, motor accidents, or objects falling on the head from a height. Many of these wounds, but by no means all of them, are of the so-called nonpenetrating type

Obviously what the first author says concerning injuries of the one type often will be said also by the second author concerning injuries of the other type. Although this does not constitute overlapping, in the usual sense, the reader may wish to cross-refer at times. Therefore, many cross references have been supplied.

GUNSHOT OR SHELL WOUNDS OF SCALP SKULL, AND BRAIN

PROPHYLAXIS

It would be of the greatest possible benefit if soldiers could all go into action with closely cropped hair It is a self-evident fact that long hair matted and often hardened with clotted blood, is difficult to make clean, requires much more time to remove and involves a slow and painful process in its removal. Futhermore, long hairs driven into the brain form added infected material.

Immunization against Tetanus

All personnel of the Army is immunized actively against tetanus by vaccination with *tetanus toxoid* (plain) The initial series is given

as soon as possible after each individual enters the service It consists of three subcutaneous injections of the toxoid at intervals of three to four weeks, each injection being 1 cc in amount. A stimulating dose of 1 cc normally will be given at the end of the first year only However, if an individual is to depart for a theater of operations he is given a stimulating dose of 1 cc unless such departure is within a period of six months subsequent to the stimulating dose given at the end of the first year The record of tetanus vaccinations is stamped on the identification tags of the individual. Immunity lasts from six months to five years Untoward reactions are rare An emergency stimulating dose of 1 cc. of tetanus toxoid is administered to any previously vaccinated individual who incurs a battle wound or burn, or any nonbattle injury in which tetanus is feared, or who is to undergo a secondary operation for which the surgeon deems tetanus toxoid advisable.

All personnel of the Navy is also immunized actively against tetanus but the system differs in several respects from that employed in the Army

1 Alum precipitated toxoid is employed instead of plain toxoid
2 Each dose is 0 5 cc instead of 1 cc
3 The initial series consists of two injections at intervals of four to eight weeks
4 A stimulating dose of 0 5 cc is given at the end of one year and if the individual is wounded.

If tetanus toxoid has not been given, *tetanus antitoxin* (1500 units) should be given intramuscularly at the earliest possible moment after the infliction of a wound of any type except those which are trivial and superficial. A second injection of like dosage should be given after subsequent operation. Such injections should be recorded on the soldier's emergency medical tag as to the time, place, and amount injected.

GENERAL CONSIDERATIONS

Records

It is of the greatest importance in all cases of head injury that a record be made of the patient's symptoms and signs at all stages of his progress, so far as this is feasible This record should be entered on the man's emergency medical tag at the earliest dressing station and subsequent records should be entered at any other hospitals to which the patient may be taken. This record should indicate any evidence of damage to the brain (paralysis, focal or other convulsions, aphasia, sensory loss, ataxia, and so forth) Other points are the state of consciousness, condition of pupils, and pulse rate

This knowledge will be of the greatest value to those who have to deal with the treatment of the wounded at later stages. These records may be the only guides as to the diagnosis of a meningeal or subdural hematoma.

So far as conditions permit, a brief history and results of a neurologic examination should be recorded at the hospital where complete débridement of the wound has been done. Results of subsequent neurologic examinations should be recorded as the patient's signs and symptoms become better or worse. These records are important, not only in the making of decisions as to further indications for treatment (such as the development of meningitis or abscess of the brain) but for correlation of data which can be used eventually for investigative purposes.

TREATMENT GIVEN

Morphine given Dose
Sulfonamide given Dose
Antitetanic serum given Dose

Progress under Observation

Improved? Stationary? Worse?

Remarks

Signature of M.D

All questions marked with interrogation mark to be answered with + = Yes O = No. At each station or hospital a new card must be filled in and placed with the other cards in the patient's envelope

Fold along this line

HEAD INJURY CARD

For use at all medical stations from front to base.

No. Name
Rank Unit

Date and time of injury
Date and time of examination
External injury? Fracture seen?
Fissured? Depressed?
(Site of external wounds to be marked on diagrams on back of this card.)*

Mental state
I. Alert? Drowsy? Comatose?
II. Lucid? Confused?
III. Quiet? Excited? Irritable?
Pupils Dilated? Pin point?
Equal? R. larger? L. larger?
Weakness or paralysis?
Right limbs? Left limbs?
Pulse rate Fits?
Respiration rate

* These diagrams are outline drawings of the face, of the top of the head, and of right and left sides of head (Fig. 1)

Field Medical Card—A convenient and efficient method of recording is to fill a field medical card similar to that used in the British Medical Service a suggestion of which is given above. At each

as soon as possible after each individual enters the service It consists of three subcutaneous injections of the toxoid at intervals of three to four weeks, each injection being 1 cc in amount. A stimulating dose of 1 cc normally will be given at the end of the first year only However, if an individual is to depart for a theater of operations he is given a stimulating dose of 1 cc unless such departure is within a period of six months subsequent to the stimulating dose given at the end of the first year. The record of tetanus vaccinations is stamped on the identification tags of the individual Immunity lasts from six months to five years Untoward reactions are rare An emergency stimulating dose of 1 cc of tetanus toxoid is administered to any previously vaccinated individual who incurs a battle wound or burn, or any nonbattle injury in which tetanus is feared, or who is to undergo a secondary operation for which the surgeon deems tetanus toxoid advisable

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the last group there will be several subdivisions, since the operative treatment varies considerably with different types of penetrating wounds. These divisions will appear presently

Objects of Treatment

In a general way the objects of any treatment for shell wounds of the brain and its envelopes are exactly the same as for wounds of all other tissues, namely, complete and thorough *removal* by operative measures of all dirty contaminated, or devitalized tissue from the skin inward, together with removal of all retained foreign bodies —fragments of bone, hair clothing, and pieces of metal, with certain exceptions in respect to the latter as will be explained in detail in the proper place. As with other tissues, so with respect to the brain, débridement should be accomplished without further loss of physiologic function or excision of clean, normal tissue, except in so far as it may be advisable in order to make certain that all dirty or infected material has been eliminated. Débridement of every wound should be done at the earliest opportunity to do it thoroughly so that contaminated open wounds may be converted into closed clean ones as quickly as possible.

General Treatment

Certain other generalized lines of treatment should be mentioned, since they may be applicable at any point, from the battalion aid stations down to the general hospitals. The following two paragraphs are taken substantially from "Memorandum of the Treatment of Head Injuries" by Prof Hugh Cairns

General treatment will be determined by (1) the clinical evidence of injury to the brain, and (2) the nature of the wound, if one is present. As already emphasized, it is of the utmost importance that in all cases of injury to the head, except for the most trivial injuries, a neurologic examination be made and results recorded and, if necessary, repeated later on each occasion the record being entered on a field card.

The general plan of treatment for the patient who is unconscious after an injury to the head, whether open or closed, is the same. The most important principles of nursing are to maintain a free airway and assurance that food and oral secretions do not get into the trachea, for if they do get in they may cause pneumonia, which usually is fatal (see also p. 29) The patient should be laid on his side but he should be turned from one side to the other every four hours, and, in addition, his position should be slightly altered

medical station to which the man is sent a new card is filled in by the medical officer, so that any changes in the patient's condition for better or for worse are thus recorded. The card should be in such form that when it is folded once it will fit into an evelope of water-proof paper which is attached to the man's clothing The information to be noted on such a card so far as head injuries are concerned has been indicated in the foregoing form

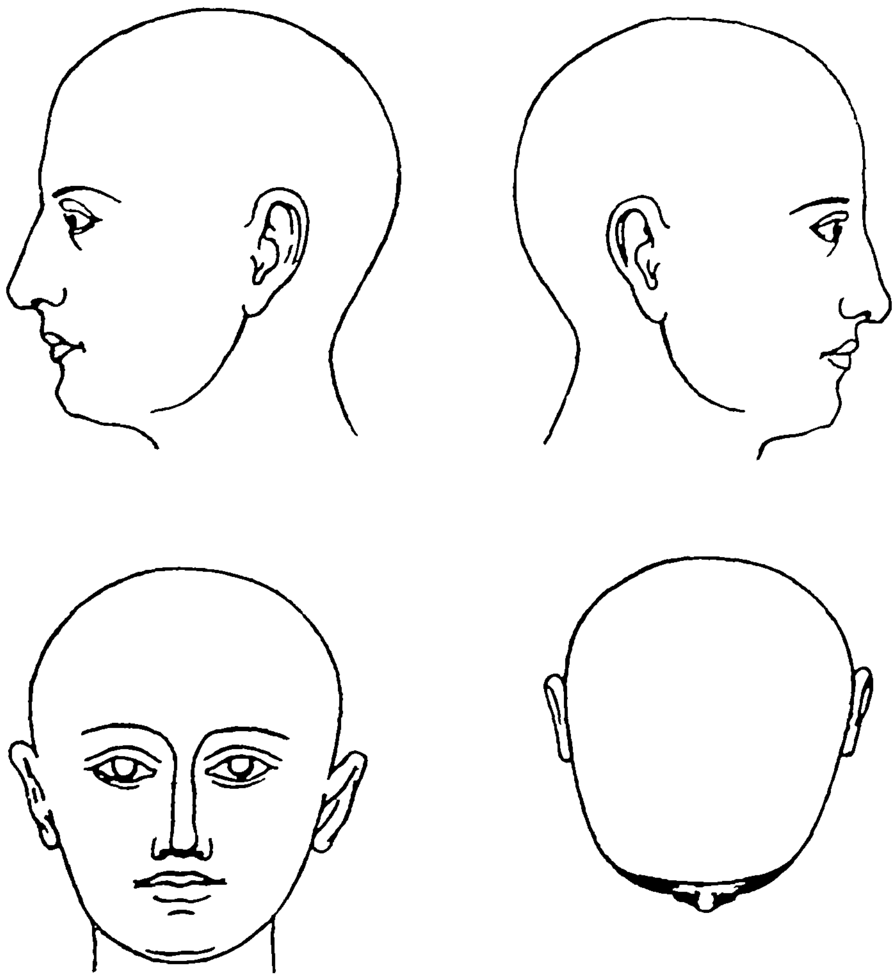

Fig 1—Outline drawings that are printed on the field medical card

Three Divisions of the Subject

After consideration, it seems that gunshot wounds of the scalp, skull and brain might be considered best under three main headings, namely, wounds of the scalp, fracture of the skull without penetration of the dura, and fracture in which the dura has been penetrated In

Sulfanilamide

This drug should be given orally to all patients, including those who have purely scalp wounds, unless it is possible to operate on the latter within twelve hours. The first dose of sulfanilamide should be given as soon as possible after the wound has been received and the amount and time (day and hour) of administration should be noted on the soldier's emergency medical tag. If the patient is unable to swallow, it should be given by nasal tube. The initial dose should be 2 gm. and subsequently 1 gm. every six hours should be administered (see also p. 38) In all cases, the amounts administered should be noted on the emergency medical tag, together with the day and hour given.

Transportation

This should be accomplished with all possible speed but with the utmost in gentleness, especially in respect to those whose head wounds are obviously serious and extensive. In transportation by air it should be remembered that patients who have wounds penetrating the brain do not tolerate high altitudes (that is, more than 4500 feet) well. High altitude increases headache and vomiting and causes further protrusion of an already existing brain fungus. Soldiers who have penetrating fractures of the skull never should be taken above an altitude of 12 000 feet (see also p. 32) An unconscious patient should be placed on his side, in a position in which breathing is free.

WOUNDS OF SCALP

First Aid and Emergency Treatment

Scalp wounds may be small insignificant cuts or they may be extensive, jagged, dirty lacerations of almost any size. Hemorrhage may be severe, especially in association with wounds of the temporal and occipital regions. Most men who have purely scalp wounds will be able to make their own way back to the battalion aid station but if there has been considerable laceration, with hemorrhage, they may have to be carried in. Those in this latter class should be sent back to a place in which fluids can be replaced as rapidly as possible.

To most scalp wounds merely a dressing should be applied at the first-aid post. This should be, preferably, of vaselined gauze, or sterile vaseline can be put on the wound and then dry gauze can be applied over this. Another excellent dressing is gauze soaked in an oily solution of N N-dichloroazodicarbonamidine (azochloramid)

at more frequent intervals If there is the slightest evidence of coughing or choking on swallowing, it is advisable to pass a rubber tube through the nose and down into the stomach and to feed the patient through this tube The tube can be strapped to the cheek and left in place for days at a time, and it should be retained until the patient can swallow well If breathing is embarrassed by oral secretions, the foot of the bed should be raised, the secretions then dribble out of the mouth or they can be removed by suction if such is available

Treatment of Shock

A small hypodermic injection of *morphine* (1/8 to 1/6 grain or 0 008 to 0 01 gm) should, as a rule, be the first therapeutic measure It must be remembered, however, that the effects of morphine may mask symptoms of increased intracranial pressure, and also that they may depress the central mechanism of respiration to a dangerous degree, nevertheless, small amounts of this drug, given judicially, are often beneficial. Later, at the time of operation, larger doses of morphine (1/4 to 1/3 grain or 0 016 to 0 02 gm) are well tolerated.

Further methods of combating shock include quiet so far as this is obtainable, warmth, the continuous intravenous drip of physiologic saline solution, or intravenous administration of plasma and transfusions of blood Prolonged treatment for shock in the presence of cranial wounds, however, is usually unwise It is of the utmost importance to get patients to a station where a complete operation can be done, with primary closure of the wound These operations can be performed with the patient under the influence of local anesthesia with morphine, consequently, the patient can be warmed and given fluids during the course of the operation.

Delirium and Convulsions

These may be present in any case of serious head wound, and they should be combated by such sedative measures as the administration of *luminal sodium* (1½ to 3 grains or 0 1 to 0 2 gm) intravenously, of *chloral hydrate* (20 to 30 grains or 1 3 to 2 gm) by mouth or rectum, or *phenobarbital* (1½ to 3 grains or 0 1 to 0 2 gm) by mouth if the patient is conscious When patients are unmanageable, fairly large doses may be required Small doses of *morphine* (1/6 grain or 0 01 gm) also may be used

Multiple Wounds

Careful examination always should be made for wounds in all parts of the body, as well as for multiple head wounds

(ST37), or a 1 3000 aqueous solution of azochloramid. All wounds should be freely irrigated with warm physiologic saline solution. The dirty edges of the wound are then excised, excision extending down through galea and periosteum, if these structures have been involved and are contaminated. It is unnecessary to remove more than the merest edge of the contused scalp Sometimes the missile will have cut through the periosteum and made a slight groove in the bone If the roentgenogram shows no depressed fragments of the inner table under this area treatment may be that of a simple scalp wound. Excision of a dirty portion of scalp and underlying tissues should be carried out en bloc and the instruments used for this should be discarded.

Wound Closure.—After cleansing and débridement as described immediately previously the wound, if operated on within twelve hours of infliction, should be closed completely with fine silk when possible, with one layer buried in the galea and a second layer placed in the skin. Before closure, *sulfanilamide powder* should be dusted into the wound.

If débridement of the wound has taken place more than twelve hours after infliction, primary closure can be undertaken if obvious infection is not present and if the patient can be kept under observation by the surgeon for several days. If the patient is to be evacuated immediately the wound should be packed widely open, either with sterile vaseline over which is placed dry gauze, or with some form of mildly antiseptic ointment. *Sulfanilamide* or *sulfathiazole powder* should be used in the wound.

WOUNDS ACCOMPANIED BY SKULL FRACTURE WITHOUT PENETRATION OF DURA

First Aid and Emergency Treatment

It is not always possible at forward dressing stations to distinguish wounds of this type from purely scalp wounds or from those accompanied by dural penetration. In any case, treatment should be similar to that of scalp wounds, so far as dressing is concerned. Men who have sustained wounds of this nature, as a rule, exhibit the results of a more serious injury that is, some degree of shock, unconsciousness, or partial loss of consciousness, and many give neurologic evidence of damage to the brain—paralysis, aphasia, temporary hemianopsia, and so forth. It is essential to transport men with this type of wound back to a place in which they can be operated on with as little delay as possible since complete recovery may be looked for in the vast majority of cases in which careful débridement can be performed within twelve hours after the patients were wounded. Some

Placing of dry gauze next to a raw surface never is advisable * If hemorrhage is a factor it can be controlled with tight packing and bandaging Occasionally it may be necessary to place a hemostat on the bleeding vessel and leave it there If time serves, the more simple types of scalp wounds might be cleansed thoroughly with soap and water, the hair clipped or shaved away around the laceration and a clean, vaseline and gauze dressing applied after using *sulfanilamide powder* in the wound Before clipping or shaving, the wound should be packed lightly with gauze, to keep the hairs and dirt out of the wound

Definitive Treatment

Wounded men ordinarily should arrive at stations where definitive treatment can be carried out within four to twelve hours after being wounded (see also p 30) It is here that thorough and complete débridement of all wounds should be done, so far as it proves to be possible In times of stress, the wounds of such patients as need immediate or urgent attention should be treated first and all others in order of expediency

Inspection of Wound—Every scalp wound, no matter how trifling, may be a penetrating wound of the skull Many penetrating wounds are encountered among walking wounded men For this reason all scalp wounds should be inspected with the greatest care and the whole head should be shaved if there is any possibility of multiple or possibly penetrating wounds In case there is a suspicion of the latter, roentgenograms of the whole skull should be made so that the examiners can be perfectly sure as to fracture or retention of a foreign body Some men who appear merely to have scalp wounds will show evidences of contusion of the brain A neurologic examination should be made in these cases and the salient features recorded on the man's emergency medical tag

Operative Procedures—Wounds which prove to be purely injuries of the scalp should be thoroughly washed with soap and water A considerable area around the wound should be shaved and prepared with 70 per cent alcohol and 1 1000 solution of bichloride of mercury, or with iodine and alcohol The wounded region should then be infiltrated with a solution of 1 per cent *procaine hydrochloride,* to each ounce (30 cc) of which 3 drops of *epinephrine solution,* 1 1000, has been added The wound itself is next cleaned with a solution of either bichloride of mercury 1 1000, full-strength hexylresorcinol

* If definitive treatment is to be carried out within a few hours, it is permissible to use some form of sulfonamide powder and dry gauze on a scalp wound

(ST37) or a 1 3000 aqueous solution of azochloramid. All wounds should be freely irrigated with warm physiologic saline solution. The dirty edges of the wound are then excised, excision extending down through galea and periosteum, if these structures have been involved and are contaminated. It is unnecessary to remove more than the merest edge of the contused scalp. Sometimes the missile will have cut through the periosteum and made a slight groove in the bone. If the roentgenogram shows no depressed fragments of the inner table under this area treatment may be that of a simple scalp wound. Excision of a dirty portion of scalp and underlying tissues should be carried out en bloc and the instruments used for this should be discarded.

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It is not always possible at forward dressing stations to distinguish wounds of this type from purely scalp wounds or from those accompanied by dural penetration. In any case, treatment should be similar to that of scalp wounds, so far as dressing is concerned. Men who have sustained wounds of this nature, as a rule, exhibit the results of a more serious injury that is, some degree of shock, unconsciousness, or partial loss of consciousness, and many give neurologic evidence of damage to the brain—paralysis, aphasia, temporary hemianopsia, and so forth. It is essential to transport men with this type of wound back to a place in which they can be operated on with as little delay as possible, since complete recovery may be looked for in the vast majority of cases in which careful débridement can be performed within twelve hours after the patients were wounded. Some

of the wounded men in this category will be capable of being evacuated sitting in an ambulance or airplane but the more seriously injured will need to be carried on stretchers

Serious hemorrhage must be checked by the use of a pressure bandage after vaseline and gauze have been applied to the wound Here again, if there is time to do so, careful shaving of the area about the wound before dressing will prevent subsequent infection to some extent, but nothing should be done to the broken bone even when it is visible *Sulfanilamide powder* should be used in the wound If he is in a state of shock, the patient should be covered with blankets and given hot-water bottles and a hot drink if conscious, and evacuation should be carried out with the greatest possible care and gentleness If shock is profound it may be necessary to delay evacuation for an hour or two, if the wounded man can be put in a quiet, warm place Too long a delay, however, is not justified, since early débridement is of prime importance

Definitive Treatment

Men who still give evidence of a fairly marked degree of shock should continue to be treated for this, perhaps in a special ward, hut, or tent for this purpose, but it is to be reiterated that treatment for shock never should be continued beyond the time when primary débridement and closure should be done, except under the most extraordinary circumstances.

After shaving the whole head (if this was not done as a first-aid measure), and inspecting it for other wounds, stereoscopic lateral roentgenograms, together with anteroposterior and postero-anterior or tangential roentgenograms, should be made so that the extent of fracture and the extent of depression of any fragment can be ascertained. A brief neurologic examination should then be made to determine to what degree there has been contusion or other damage to the brain It is important to know the neurologic status of a patient, because the examiner may be guided by such knowledge as to what is to be done at operation or as to what may have to be done subsequently The patient is now ready for operation

Types of Wounds—Gunshot fractures of the skull without penetration of the dura are essentially of two types First are the *tangential wounds,* which plough through the scalp and glance off the bone These cut a long furrow in the scalp, large or small, smooth or rough, according to the size and shape of the missile The outer table may or may not be fractured, but the inner table usually is broken up to some extent and the fragments depress the dura Second

are the wounds inflicted when a spent missile penetrates the scalp and indents the bone, as in a blow from a blunt instrument sustained in civil life, making the so-called *pond-shaped depressed fracture*. Sometimes the missile will be found to be lodged in the bone itself.

Operative Procedures.—Operations for either of the foregoing types of fracture vary somewhat according to the extent and dirtiness of the scalp wound, and according to the character of depression of the inner table. *Procaine hydrochloride* with *epinephrine* as in scalp wounds, is the preferable anesthetic agent almost always it is sufficient unless the patient is extremely unruly A hypodermic injection of *morphine* (1/8 to 1/4 grain or 0.008 to 0.016 gm.) should precede the operation by a half hour

EXTENSIVE WOUNDS.—If the scalp wound is extensive, with much laceration, and therefore débridement is difficult, it is probable that the bone likewise will be considerably broken up. In this case it will be better to take out all the depressed fragments of bone and leave them out, doing primary suture, of course, if operation has taken place less than twelve hours after the wound was received. Again, the local use of *sulfanilamide powder* is important.

SLIGHT DEPRESSION WITHOUT CONTAMINATION BENEATH THE BONE.—When wounds are small and fairly clean it is often possible to do much less than this. The contaminated scalp and periosteum are cut away carefully and the instruments with which this was done are discarded. A bur opening is then made just outside the depressed region and the dura is exposed over a small area. A smooth, blunt instrument can then be introduced between dura and bone with this it can be ascertained whether any spicules are protruding through the dura. If not, it may be possible to elevate the depressed bone by pressing outward with the instrument. If this is possible nothing further need be done except closure of the scalp in the usual way This method should be used only when depression is slight and when the surgeon is sure there is no contamination beneath the bone.

EXTENSIVE DEPRESSION WITHOUT SEVERE CONTAMINATION.—If the depression is extensive, several bur holes can be made around it and from these the depressed bone can be elevated as just described, or it can be taken out en bloc. If the bone has not been badly contaminated, it may be advantageous to replace several of the perfectly clean fragments and then carry out primary closure of the scalp (see also p. 39) Such a procedure will obviate the leaving behind of a large bony defect which might have to be filled in later

INSPECTION FOR DURAL PENETRATION—The surgeon must always make sure that dural penetration either has or has not occurred in these fractures, by feeling with a blunt instrument or by taking out the depressed portion and inspecting the dura if there is doubt concerning such an occurrence, because the evidence disclosed in even the best roentgenograms is not always conclusive on this point

DEPRESSION WITH SEVERE CONTAMINATION—In some types of depressed fracture, even though the dura has not been pierced, both the outer and inner tables will be found to be broken up and contaminated badly with dirt, hair, bits of clothing, and so forth In such cases, not only the scalp and periosteum, but also the whole portion of involved bone, must be taken out completely and no attempt at any replacement of bone should be made For removal, several bur holes are made around the depression and these openings are connected with each other by means of a cutting forceps such as a Montenovesi instrument Thus, the piece involved can be lifted out en bloc, without contamination of other structures. Again, primary closure is indicated if the wound is less than twelve hours old Free irrigation of all these wounds with physiologic saline solution during operation is most essential, and before closure *sulfanilamide powder* should be used locally

REMOVAL OF CLOT—It is in the type of injury under discussion that the question arises occasionally as to whether or not the dura should be opened for evacuation of an underlying clot or for removal of contused, softened, and devitalized brain tissue Neurologically, such patients often give evidence of considerable damage to the brain or of the results of pressure on the involved portion. A much more rapid and more satisfactory recovery will follow if clots of this kind can be removed at operation but the danger of infection is so great that ordinarily the risk should not be taken, even with wounds seen within the period of twelve hours However, when neurologic signs and the region visualized at operation, together with evidence of considerably increased intracranial pressure, point to a large clot which in itself endangers life, then the dura should be opened, the clot evacuated, and the dura resutured Resuture of the dura should be carried out with the greatest care, to achieve accurate approximation, with fine silk sutures on round, curved "French" needles Primary closure of the scalp is indicated if the previously defined time interval has not been exceeded. The dura never should be opened by those who are inexperienced in neurosurgical procedures

Treatment after Lapse of Twenty Four to Seventy-Two Hours.—When wounded persons arrive, after a lapse of twenty four to seventy two hours, at stations where definitive treatment is given, there will almost never be any occasion to treat for shock (see also p. 32) The man either will have died from shock or will have recovered from it. Neurologic examination and roentgenograms of the skull are first in order followed by shaving of the whole head, inspection of the wound, and careful search for other wounds which may have been covered with hair

OPERATIVE PROCEDURES.—Again, *procaine hydrochloride* with *epinephrine* is the anesthetic agent of choice, but after a lapse of from one to three days, with wounds infected and perhaps the beginning of general infection, more patients are unruly or intolerant of operations performed under local anesthesia, and anesthesia with *ether* or *avertin* and *ether* will be necessary more often than it was at earlier operations. Even so, the majority of operations can be done under procaine with the judicious use of *morphine* as an adjunct.

Unless the use of *sulfanilamide* prevents infection, skull fractures from gunshot without penetration of the dura should be treated as infected wounds. The dirty portion of scalp and periosteum is first cut away and radiating incisions are made from the wound in order to get good exposure of the depressed portion. The scalp flaps are spread by means of self retaining retractors. The depressed area is surrounded by bur holes and excised en bloc, in the same way as was described just previously However no fragments of bone should ever be replaced, and the wound should be left widely open. The dura should not be opened at the site of the wound (see also p. 39) If an underlying clot is present, or circumstances render decompression necessary it should be done on the opposite side. If the clot still endangers life in spite of the decompression carried out on the opposite side, it may in rare instances have to be evacuated after the rest of the wound has been packed off and the dura has been washed with full-strength hexylresorcinol (ST37) or other similar antiseptic solution. Under these conditions the dura should be closed again, but the rest of the wound should be left widely open, by packing lightly with vaselined gauze, or better still by the placing of thin gutta percha tissue next to the surface of the wound, and then gauze above the gutta percha. *Sulfanilamide powder* always should be used locally in these wounds. *Sulfathiazole powder* may be used on the scalp and bone but should never come into contact with the brain (see also p. 196)

WOUNDS ACCOMPANIED BY PENETRATION OF DURA

The Four Types

Under this heading will be considered the four principal types of penetrating wounds

1. Dura slightly punctured
2. Dura widely torn, fragments of bone, with or without metallic foreign bodies, deeply indriven.
3. Through-and-through (perforating) wounds
4. Craniofacial wounds (involving air sinuses)

First Aid and Emergency Treatment

For all types of penetrating wounds the treatment is similar at the battalion aid station A dressing of vaseline and gauze should be applied, as to the less serious wounds, no attempt being made to carry out any type of treatment of the fracture itself unless loose, superficial fragments of bone are found which can be picked out easily

Men who have penetrating wounds are frequently in a condition of serious shock and this must be combated at once by the usual methods—a hot drink (tea), hot-water bottles, warm blankets, and a quiet place if one can be found Rapid, but gentle evacuation to the nearest station at which permanent treatment can be instituted is of the utmost importance Judicious use of *morphine* and, if the patient is conscious, a cigarette, sometimes are comforting and soothing The same can be said of a drachm (4 cc) or two of brandy in hot tea * Again it should be emphasized that prolonged treatment for shock is unnecessary and undesirable in the presence of cranial injuries The importance of getting the patients back to a station at which a complete operation can be performed is great

Definitive Treatment

It is at surgical or evacuation hospitals that most of the serious operations will be done unless transportation by air can be utilized on a large scale to take wounded men directly and quickly to general hospitals It is therefore appropriate at this point, before much is written about these most frequent and most serious of head wounds, to include something about operating-room facilities, anesthesia, and general arrangements for the seriously wounded

Tent or Hut Hospitals in Field—If they are in a forward area, the wounded persons will be brought to the hospital by ambulance

* These latter were recommended by Dr Daniel E Pugh, an American who served with a British battalion in the war of 1914–1918

There should be a receiving tent or hut, as the case may be, at which there is a medical officer who distributes the wounded men to the various units (to be mentioned) according to their general condition. From the receiving station, patients who are in a condition of serious shock should be sent to a resuscitation ward (tent or hut), whichever the case may be. Here patients should be treated intensively for their general condition—such measures being used as the intravenous administration of fluid or plasma and transfusion of blood—as well as for shock, with the methods already mentioned. Under no circumstances, however, should men be allowed to stay in this ward beyond the time limit during which they could have been operated on and could have had their wounds closed by primary suture. There is never any necessity for such delay and the danger to their lives is greater if they are not operated on within the twelve-hour limit than is the danger from their condition of shock. It should be noted here that to those not familiar with injuries to the head, patients who have sustained gunshot wounds of the brain may appear to be in a state of shock when in reality they are suffering merely from increasing intracranial pressure. In other words, they may be unconscious or semiconscious, with rapid pulse and clammy skin, rapid or stertorous breathing, and pupils which do not react to light. Such patients, if they can be saved at all, are in immediate and urgent need of reduction of intracranial pressure by operation, therefore, to treat them for shock not only is unwarranted but robs them of their one chance of recovery

Preoperative Ward—Wounded persons, other than those in a state of shock, should be sent to a "preoperative" ward (tent or hut) where they can be examined from the neurologic standpoint and where the salient points of such an examination can be noted on their emergency medical tag or on a brief history sheet. A simple way to carry out such a procedure is to have some form of blank book with carbon paper available so that the original record can be kept and the duplicate can be sent on in the soldier's field envelope. In this preoperative ward, also, clothing can be removed, a sponge bath can be given, and the patient can be made ready for operation in any other way necessary

Operating-Room Arrangements.—It is well to bear in mind the consideration that in war a large number of casualties often may have to be cared for in as brief a time as possible. This is particularly true when it is advisable to accomplish thorough débridement and primary closure. Everything therefore that facilitates the handling of patients without loss of time is of the utmost importance. For

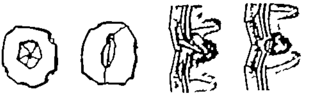
this purpose it would be advantageous if one or more extra tables could be placed in the operating tent or hut These need be only simple wire frame or wooden tables, not elaborate operating tables In fact, even the latter should be as simple as possible, with arrangements for only an extension head rest for patients being operated on in the cerebellar position, and some simple device for raising and lowering the head of the table Square sandbags measuring 8 by 8 inches (about 20 cm) should be available to place under the patient's head The reason for the extra table or tables is that patients can be "fed in," so to speak, without loss of time Thus, while one patient is being operated on, another patient on one of the extra tables can be having his head shaved and, on still a second extra table, a patient whose head already has been shaved can be given preliminary treatment by infiltration of the operative area with procaine hydrochloride by the surgeon, who has dropped out of the preceding operation while his assistant is making the closure The patient then simply is lifted over to the operating table This procedure eliminates much loss of time in sending for and bringing patients from the resuscitation and preoperative wards or tents Arrangements similar to this one were utilized during the war of 1914–1918 at forward areas in the British service, and were found to be highly satisfactory

Anesthesia—Under previous sections mention has been made of *procaine hydrochloride* as the anesthetic agent of choice in the treatment of gunshot wounds of the skull and brain In the war of 1914–1918 this was the consensus of the outstanding neurologic surgeons of the time and, from all aspects, it would seem still to be the most useful anesthetic The advantages of procaine hydrochloride (with the addition of 1·1000 solution of *epinephrine* in the amount of 3 to 6 drops per ounce [30 cc] of procaine) are as follows Hemorrhage from the scalp is minimal because of the action of the epinephrine Local anesthesia encourages delicate handling of tissues, a feature of extreme importance at any time and particularly in operating on the brain There is no need of hurry and hence no urge to hurry when a patient is under anesthesia with procaine hydrochloride, and for this reason thorough and complete débridement is encouraged. The importance of this point cannot be overestimated, since the success of operation in the presence of gunshot wounds depends on the removal of all foreign material During an operation under procaine the patient often can cooperate with the surgeon Other factors in favor of anesthesia produced with procaine hydrochloride are its

safety the easy postoperative course of the patient, and the fact that a trained anesthetist is not always necessary

In speaking of anesthesia, however it must be understood that although procaine hydrochloride probably is the most useful agent, and should be utilized more than any other there are obviously times when *general anesthesia* will have to be employed. Some patients suffering from multiple wounds which have to be treated certainly require general anesthesia and certain patients with wounds of the head will be entirely unruly or too highly keyed up to make possible the use of a local anesthetic agent. Under these circumstances ether, pentothal sodium, or such other general anesthetic agents, as the surgeon and the anesthetist may choose, will have to be administered.

The judicious use of *morphine* as an adjunct to local anesthesia is of the utmost help. An initial dose of ¼ to ⅓ gram (0.016 to 0.02 gm.) given one-half hour before operation and small doses (⅙ grain or 0.01 gm.) repeated in the course of the operation add materially



Local contusions inevitable usually with positive neurological signs; cerebral extrusion uncommon.

Fig. 2.—Diagrammatic representation of wound with dura slightly punctured (after Cushing Brit. J Surg.)

to the comfort of both patient and surgeon, and enhance the effect of procaine hydrochloride to a remarkable degree.

Operative Procedures. DURA SLIGHTLY PUNCTURED.—Wounds of this nature (Fig. 2) wherein a spicule of bone from the inner table has pierced the dura, should be treated in general as simple depressed fractures are treated. This means careful débridement of scalp and periosteum after which radial incisions (two or three) should be made to extend out from the wound in such manner as to obtain good exposure on the bony area. In these cases the portion of bone involved should be removed en bloc by the usual method of making bur holes around the area and connecting these with cutting forceps. If the dura has sustained only one or two small punctures, nothing need be done except secure closure of the scalp Occasionally even some of the fragments of bone can be replaced if they are clean. If there is any doubt as to cleanliness, however this never should be done If the dura is considerably torn it may be necessary to flush out softened brain or superficial clots by means of gentle irrigation with

this purpose it would be advantageous if one or more extra tables could be placed in the operating tent or hut. These need be only simple wire frame or wooden tables, not elaborate operating tables In fact, even the latter should be as simple as possible, with arrangements for only an extension head rest for patients being operated on in the cerebellar position, and some simple device for raising and lowering the head of the table Square sandbags measuring 8 by 8 inches (about 20 cm) should be available to place under the patient's head The reason for the extra table or tables is that patients can be "fed in," so to speak, without loss of time Thus, while one patient is being operated on, another patient on one of the extra tables can be having his head shaved and, on still a second extra table, a patient whose head already has been shaved can be given preliminary treatment by infiltration of the operative area with procaine hydrochloride by the surgeon, who has dropped out of the preceding operation while his assistant is making the closure The patient then simply is lifted over to the operating table This procedure eliminates much loss of time in sending for and bringing patients from the resuscitation and preoperative wards or tents Arrangements similar to this one were utilized during the war of 1914–1918 at forward areas in the British service, and were found to be highly satisfactory

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wound of entrance and a much larger wound of exit (Fig. 5) The other of the two is perhaps the more fatal and is that in which the missile has entered and passed through one of the *air sinuses* and

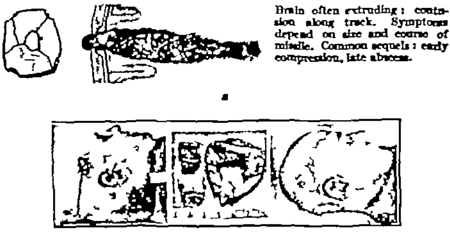

Fig. 4.—*a*, Small penetrating wound with indriven fragments of bone and retained metallic foreign body; *b* penetrating wound before and after operation (after Cushing Brit. J Surg.)

then penetrated the brain, the great difficulty in such a case being the continuation of infection (Fig. 6) It is possible that the giving of sulfanilamide may lessen greatly the hazards of such wounds.

Fig. 5.—Perforating (through-and-through) shell or bullet wound (after Cushing: Brit. J Surg.)

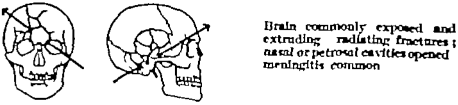

Fig. 6.—Wounds passing through air sinuses and brain (after Cushing Brit. J Surg.)

1 The Principal Surgical Problem.—The surgical problem involved in all these injuries is essentially the same: namely careful, painstaking, and complete removal of all foreign material in the brain

warm saline solution The ordinary glass syringe with a rubber bulb on one end is the most useful instrument for this purpose No fragments of bone ever should be replaced if the dura is considerably torn

DURA WIDELY TORN AND FRAGMENTS OF BONE WITH OR WITHOUT METALLIC OR OTHER FOREIGN BODIES DRIVEN DEEPLY INTO BRAIN.—Under this heading are grouped the most serious and yet extremely frequent types of gunshot wounds of the brain There is considerable variation in their extent and severity, depending on the type and size of the missile, and the manner and force with which it has struck the skull Thus large, open wounds of the *gutter* type may occur, in which the missile has ploughed through scalp and bone, showering fragments of bone to any depth in the brain at right angles to its course (Fig 3) Small or large portions of brain often will be

a

b

Fig 3—*a*, Diagrammatic sketch of "gutter" wound with shower of indriven bone fragments, *b*, gutter wound before and after operation (after Cushing Brit. J Surg)

found extruding from these wounds The fragments of bone may lie fairly superficially within the brain or they may be driven down into or through one of the ventricles or even to the opposite hemisphere Obviously, ventricular penetration increases the hazard of such injuries

Other frequent penetrating wounds are those in which a missile has been driven into the skull through a relatively small hole and has *lodged* somewhere in the brain, along with fragments of bone, hair, clothing, and the like, which it has carried with it (Fig 4) Two other types of penetrating wounds will be taken up under their own heading (see p 27) and are mentioned here only because of the problem presented by fragments One of these is the wound in which the missile has passed *completely through* the head, causing a small

wound of entrance and a much larger wound of exit (Fig. 5) The other of the two is perhaps the more fatal and is that in which the missile has entered and passed through one of the *air sinuses* and

Brain often extruding; contusion along track. Symptoms depend on size and course of missile. Common sequels: early compression, late abscess.

a

b

Fig. 4.—a, Small penetrating wound with indriven fragments of bone and retained metallic foreign body; *b* penetrating wound before and after operation (after Cushing: Brit. J Surg.)

then penetrated the brain, the great difficulty in such a case being the continuation of infection (Fig. 6) It is possible that the giving of sulfanilamide may lessen greatly the hazards of such wounds.

Extensive cranial and cerebral damage common. Death usually due to intracranial hæmorrhage and compression.

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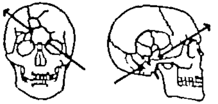

Brain commonly exposed and extruding; radiating fractures; nasal or petrosal cavities opened; meningitis common

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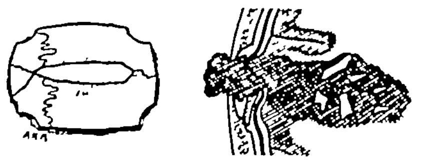

Local contusion severe, and extrusion of brain almost inevitable Fungus cerebri, encephalitis, etc, common sequels

a

b

Fig. 3—*a*, Diagrammatic sketch of "gutter" wound with shower of indriven bone fragments, *b*, gutter wound before and after operation (after Cushing Brit. J Surg)

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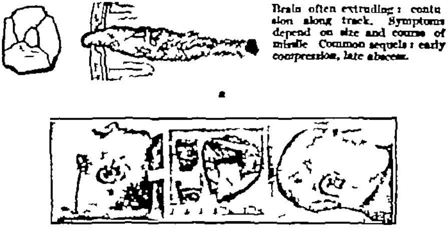

Fig. 4—a, Small penetrating wound with indriven fragments of bone and *retained metallic foreign body*; *b* *penetrating* wound *before* and *after* operation (after Cushing: Brit. J Surg)

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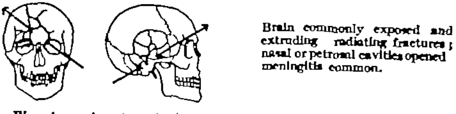

Fig. 6.—Wounds passing through air sinuses and brain (after Cushing Brit. J Surg.)

1. The Principal Surgical Problem.—The surgical problem involved in all these injuries is essentially the same namely careful, painstaking, and complete removal of all foreign material in the brain

after usual *débridement of the outer tissues, scalp, periosteum, and skull* There is one exception to this deeply indriven metallic foreign bodies If these are not fairly easily accessible it is better to leave them than to inflict additional damage to the brain by trying to get them out. Metallic fragments of small size are surprisingly well tolerated This is particularly true of the small metal splinters which frequently are showered into the brain from an exploding bomb *Such multiple small fragments almost never require operative removal* All other material, bone, clothing, dirt, hair, clots, and disorganized portions of brain should be removed by the methods to be described.

2 Excision of Scalp Wound—The scalp wound, whether it is large or small, should be completely excised, excision extending as far as normal tissue and also down through the periosteum to the skull It should be emphasized again, however, that only the least possible amount of contused scalp should be removed The instruments used for this should then be discarded Next, radiating incisions are made in the scalp in such a manner that the skin can be retracted and the area of fractured skull can be widely exposed Useful types of incisions, as demonstrated in the last war, are the "tripod" incisions which run at suitable angles from the excised scalp wound These usually can be swung one way or another at the end of the operation, so that the wound can be closed completely unless it is very large In such cases, if closure is desired, some form of plastic operation should be devised, so that a clean portion of unbroken skull remains exposed except for its covering of periosteum.

3 Excision of Skull Wounds—On exposure of the perforation in the skull by retraction of the scalp flaps, several bur holes are made around the area of bone penetration with either a hand perforator and bur or some form of motor-driven instrument These bur openings are connected by the use of a bone-cutting forceps, such as the Montenovesi instrument. The block of bone can then be lifted out intact and the skull wound thus can be excised, just as was done in the case of superficial wounds (Fig 7)

4 Cleansing and Débridement of Tract in Brain—Within the brain, at this stage, there remains the contused and contaminated tract of the missile or fragments of bone, which have been indriven, together with such other foreign matter as has been carried in

In the war of 1914–1918 it was found best to clean out this tract by the methods then available without enlargement of the dural opening, and to confine all procedures to the tract itself If strong suction and electrosurgical apparatus are not available, this procedure

would still be the method of choice. The patient (as a rule) having been given local anesthesia, he is asked to cough or strain. This tends to force softened or "pulped" brain, clots, and sometimes other material out through the dural opening, and these can then be washed away by irrigation. Next, a soft rubber catheter, to which is attached a glass syringe with a rubber bulb, is gently introduced through the dural opening and, when pressure on the rubber bulb is released, portions of softened brain, clots, and sometimes small bits of bone

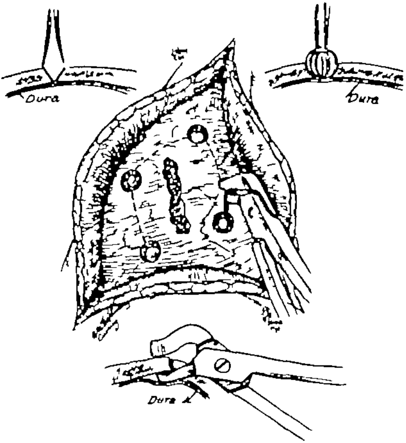

Fig. 7—Exposure of fracture and removal en bloc by bur openings and cutting forceps (after Cushing: from Horrax: Canad. M.A.J.)

are sucked up into the catheter through its eye. The catheter is then withdrawn and its contents are expressed into a suitable basin. This process is repeated time after time, in order to clean out the tract thoroughly and the suction is alternated with very gentle irrigation with physiologic saline solution (Fig. 8) The catheter likewise is used for palpation of bony fragments along the tract and, when these have been located, they are grasped by a delicate alligator forceps and withdrawn. In this way the metallic fragment also

may be palpated, usually it will be found to lie at the bottom of the tract and it too can be withdrawn with forceps or by magnetization. Magnetization is accomplished by the introduction of a round-ended nail, 3 to 5 inches (about 7 5 to 13 cm) long, into the tract until the end of the nail is in contact with the metal A strong electromagnet is then brought up to the head of the nail, and on withdrawal of the magnet and the nail, the foreign body often will be withdrawn also

Cleansing of the tract produced in deeply penetrating wounds is a long, slow, painstaking process, but the success of the operation depends on its thoroughness The number of fragments of bone indriven should be ascertained as nearly accurately as possible by the previous making of roentgenograms and every fragment should be removed if it is at all possible It is remaining fragments of bone,

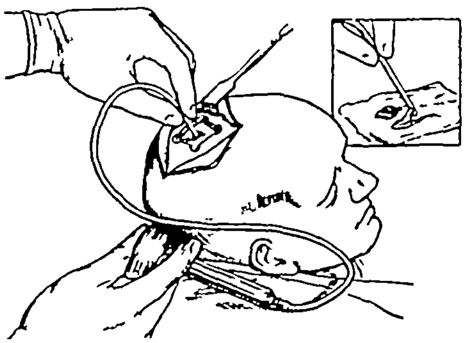

Fig 8—Method of cleaning tract in brain by suction from a catheter and irrigation (after Cushing Brit. M J)

and other material, such as clothing, which constitute the cause of subsequent infection and abscess more often than metallic foreign bodies In the cleaning out of most of the serious wounds of the type described an average of two hours was required as a rule, even by the most experienced surgeons

Under modern conditions, provided strong suction apparatus and an electrosurgical unit are at hand, it is my belief that a much more rapid and probably far more complete débridement of the dirty tract in the brain can be accomplished than formerly was possible * Débridement of scalp and bone with such instruments would be the same as previously described. If the tract in the brain is situated in one of the large "silent" areas, it is now possible to foresee much more radical débridement. This would include electrosurgical

* A neurosurgeon, recently returned from England, said that the method about to be described has been tried there with excellent results

excision around the region of dural penetration and similar incision of the cortex outside the dirty tract. Then with a combination of strong suction and electrocoagulation, a core of brain tissue including the tract could be excised, either staying outside the tract in normal brain tissue, or starting out in normal tissue and then introducing spatulas for retraction. With a metal suction tube, to which the coagulating current is kept applied, the whole contents of the tract could be sucked out cleanly under actual vision (Figs. 9 10) Fragments of bone either could be caught up with the sucker and withdrawn, or could be seen and removed with forceps. The same would be true of other foreign matter such as clothing, dirt, and hair Probably by this method, most metallic foreign bodies could be seen and extracted unless they had been driven over to the opposite hemisphere or to too great a distance otherwise. It would seem that by these means an operation of about an hour's length for each patient would be sufficient, and that the number of wounded men who could be treated in the same time as was required by the older methods would be thus doubled, probably with fewer sequelae because of more complete débridement.

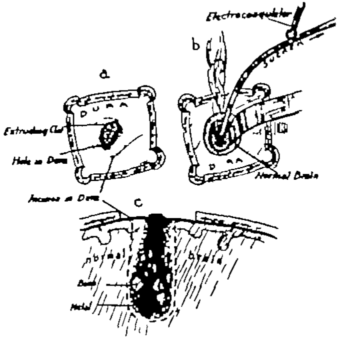

Fig. 9—Excision of tract and removal of foreign material under direct vision by the use of strong suction and electrocoagulation (after Horrax Canad. M.A.J)

Whatever method is used, if operation has taken place within

twelve hours of the infliction of the wound, after the local use of *sulfanilamide powder* primary closure should be performed If infection begins, as evidenced by local and general disturbances, the wound should be opened widely and the herniating brain should be covered with gutta-percha, cellophane, or rubber tissue

5 *Postoperative Observation*—*Since the condition of patients* who have been operated on for serious wounds of the brain must be watched carefully for complications, it is essential that no matter where they are operated on they should be able to remain there for at least two weeks If, therefore, the type of warfare current or other

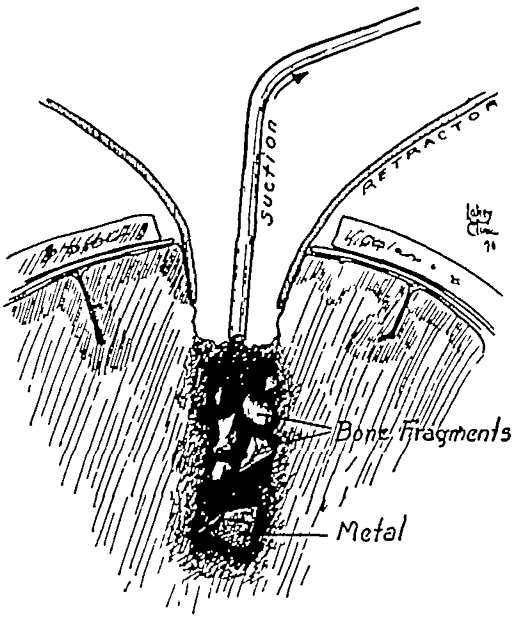

Fig 10—Introduction of spatulas on both sides of tract, clots, fragments of bone, and metallic foreign bodies are removed by suction under direct vision (after Horrax Canad M A J)

conditions are such that this is not possible it is far better to send soldiers who have penetrating wounds of the brain directly to a station where postoperative observation can be carried out. During transportation, treatment with *sulfanilamide* should be maintained to prevent infection, so far as possible (see also p 9) Some very seriously injured patients with rapidly rising intracranial pressure may have to be operated on at forward stations to save their lives, even though they have to be evacuated very shortly thereafter These patients, of course, certainly would die if they were not treated promptly, and would under no circumstances live to reach a general hospital unless transportation by air were available

THROUGH-AND-THROUGH (PERFORATING) WOUNDS AND CRANIOFACIAL WOUNDS (INVOLVING AIR SINUSES) (see also p. 20) —Two types of penetrating wounds were mentioned at the beginning of this section to these further reference should be made. They are the through-and-through or perforating wounds, which traverse some portion of the cranial chamber and the craniofacial wounds, which involve both the brain and one of the contiguous air sinuses. Both types of wounds are likely to be immediately fatal, so that not many of them are seen either at evacuation or general hospitals. Nonfatal wounds of the *first type* usually are caused by rifle or machine-gun bullets rather than by fragments of shell or bomb, and therefore the resulting wounds are less likely to be complicated by foreign matter carried in with the missile. Some patients who have through-and through bullet wounds indeed recover without any operation at all, but if they are seen at a station where major operations can be per formed the best practice is to excise both the entrance and exit wounds in the usual way, and to clean out the tract from each end so far as is practicable.

Craniofacial wounds are extremely serious because they must always be left open, and eventual infection is almost inevitable unless, now that the drugs are available, it can be overcome by the administration of one of the sulfonamides locally and by mouth. Little can be done other than to clean out the wound as thoroughly as possible, and in the case of wounds involving the frontal sinus, to take out the lacerated and contaminated portion of mucous membrane. Often these wounds will have involved one eye or even both eyes, in which case it is necessary to exenterate the ocular remnants. The brain should be protected from the open sinus by the placing of rubber or gutta-percha tissue over it and then by the packing of gauze over the tissue. Vaselined gauze may be used instead of rubber tissue. Occasionally it may be wise to close the wound when it is possible to do so, leaving a drain in place from the débrided portion down through the frontal sinus and out the nose (Cone)

Treatment of Wounds Later than Twelve Hours after Injury

Formation of Fungus Cerebri.—When patients with the types of wounds under discussion arrive at stations for definitive treat ment, after a lapse of eighteen to seventy two hours, the wound must be left widely open at the site of the injury This means a fungus cerebri of greater or less proportions will develop, and entails the greatest of care, for many days or even weeks, with meticulous dressing.

twelve hours of the infliction of the wound, after the local use of *sulfanilamide powder* primary closure should be performed If infection begins, as evidenced by local and general disturbances, the wound should be opened widely and the herniating brain should be covered with gutta-percha, cellophane, or rubber tissue.

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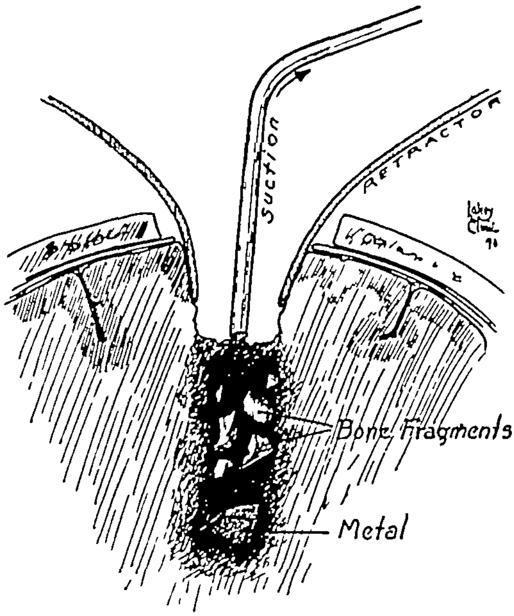

Fig 10—Introduction of spatulas on both sides of tract, clots, fragments of bone, and metallic foreign bodies are removed by suction under direct vision (after Horrax Canad M A J)

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dominantly of the nonpenetrating type. Some, of course will be penetrating in nature.

The established principles of treatment of head injuries evolved during the past two decades from a vast experience in the management of many thousands of victims of transportation and industrial accidents will find ready application in the medical care of similar injuries produced in modern war The treatment of such injuries will resolve itself into the primary care of the individual patient, whether soldier or civilian, at or near the place of injury, with transportation to, and later care at, some station or hospital in which adequate facilities are provided for any major surgical procedure.

FIRST AID CARE

Early Care and Transportation

The early treatment of the individual must of necessity be dictated to a considerable extent by the exigencies of the military situation. The patient should be brought to the first-aid post as promptly as possible so that the treatment of open wounds can be instituted early The patient should be transported (see also pp. 9 and 32) if possible, with due regard to any serious associated injuries and particularly those of the spinal column. Should there be evidence of obstruction of the airways (see also p. 7) by the accumulation of mucus, the patient had best be transported in the prone or semiprone position.

Shock

At the first-aid station it should be determined whether the patient is in a state of shock (see p. 8) Shock, however frequently is not present when the injury is confined to the head. In treatment of shock, bodily warmth should be maintained, fluids should be infused intravenously and perhaps blood should be transfused. External hemorrhage if not arrested by a pressure bandage can be controlled by the temporary application of hemostats or Michel clips to the bleeding scalp The wound, if superficial, should be irrigated with saline solution and a bandage reapplied. The head should be kept lowered until the patient responds from shock. Progress in the treatment of shock can be determined by repeated blood-pressure estimations. A systolic blood pressure of 100 or more indicates the patient is not in severe shock.

Record

A record (see also p. 4) should be made as early as possible, noting the approximate time of injury the gross evidence of injury

Postoperative Care—On completion of the operation, if "tripod" incisions have been used, the peripheral parts of these incisions may be partially closed, but the wound over the central portions, where the brain had been penetrated by the missile and where the bone was removed, must be left entirely open Gutta-percha is by far the best material to use directly over the open part of the wound, and the usual gauze bandage is placed on this If gutta-percha is lacking, any smooth material such as cellophane or vaselined gauze may be used. As the fungus develops it must be kept carefully covered with gutta-percha at each dressing, the gutta-percha being kept also between the herniation and edges of the scalp so that the two will not adhere and thus pocket the infection If the fungus becomes large, as it often does in the presence of extensive wounds, pressure should be kept away from it by the placing of a "doughnut" ring of cotton around it, over the gutta-percha, and then the gauze dressing, as usual Gradually, the surface of the fungus will granulate and, as epithelization begins to cover it over from the edges, it will recede into the cranial cavity naturally, if edema of the brain due to continued infection is not present. This, however, may be a matter of many days. Repeated lumbar puncture probably is of some help throughout this course of fungus formation, granulation, and recession but, in spite of such punctures, most of these late wounds will proceed through the aforementioned course

The surgeon should not be discouraged, even when he encounters extremely extensive and badly infected wounds Many patients, of course, will die, but many likewise can be saved by careful and thorough operation, followed by painstaking, persistent dressing, treatment of complications, and the use of sulfonamides Again it should be mentioned that *sulfanilamide powder* should be used locally in all penetrating wounds, but that *sulfathiazole powder* is contraindicated on the cortex, as it may induce convulsions

HEAD INJURIES OTHER THAN THOSE CAUSED BY GUNSHOT OR SHELL

A major activity of modern warfare is aerial bombing of cities and towns in the belligerent countries, and the victims of such attack are likely to be noncombatants, including men, women, and children. The crashing of buildings and overturning of passenger transportation units by high explosives and the collision of automobiles during blackouts are important features of modern warfare which will inevitably produce serious head and associated injuries, pre-

been added 3 drops of *epinephrine* 1 1000 to the ounce (30 cc.) of solution. Local anesthesia with or without sedatives is preferred in all operations for head trauma. If the patient is restless and can not be controlled with simpler drugs it may be necessary to supplement the local anesthesia with *rectal tribromethyl alcohol* in amylene hydrate (avertin) which is preferred to ether because of the tendency of inhalation anesthesia to raise intracranial tension. Mechanical disinfection of the scalp wound is far superior to chemical sterilization, but *sulfanilamide* or *sulfathiazole powder* should be used in the wound freely as they have been shown to have an extremely beneficial effect.* Large quantities of sodium chloride or Ringer's solution are used to cleanse the laceration. The edges of the contused laceration should be excised for a distance of about ⅛ inch (less than 0.5 cm.) and all underlying macerated tissue such as will be found in the temporal and occipital regions, removed. The wound is again freely irrigated and the scalp closed in two layers with fine interrupted silk sutures for the galea and skin. Drainage is usually unnecessary

In extensive scalp lacerations which may be partly contused and partly avulsed, débridement should be restricted to the contused part of the laceration. Lines of finger pressure along the edges of the wound are usually effective in the control of hemorrhage during débridement. Hemorrhage from scalp wounds, especially those of the temporal and occipital regions, is often profuse and every effort should be made in the repair of the laceration to keep the loss of blood at a minimum. In severe laceration of the scalp blood transfusion may be required.

The Skull

The skull beneath the laceration should be inspected and carefully palpated for fracture as soon as the wound is irrigated and before procaine is injected into the scalp. Treatment is unnecessary for a *linear fracture* beneath a laceration of the scalp unless inspection discloses debris or hair in the line of fracture. In such a case the contaminated line of fracture should be removed under conditions favorable for cranial operations. Should there be more serious open wounds of the head such as a *compound depressed fracture* with extravasation of brain tissue, the wound should be thoroughly irrigated and a sterile dressing applied until the patient can be transferred to more adequate operating facilities. Because of the probability of producing hemorrhage, no effort should be made to remove forcibly any fragment of bone unless the patient has been placed under adequate facilities for complete operation. Patients with head

* See bottoms of pages 15 and 196.

the presence or absence of shock, state of consciousness, pulse, respiration, condition of the pupils, whether there is hemorrhage from the cranial orifices, and gross signs of focal brain injury, such as weakness or paralysis of the extremities. This record should accompany the patient throughout his treatment

If the patient with an open wound has not had prophylactic *tetanus toxoid* he should be given 1500 units of *tetanus antitoxin* and this recorded on his emergency medical tag

History of the patient with respect to the state of consciousness is of the greatest importance It is desirable to know whether the patient became unconscious immediately on receiving the injury or whether he later became stuporous and finally unconscious Indications pointing to middle meningeal hemorrhage may be supplied by knowing whether a lucid interval followed the injury with later increasing stupor and the development of unconsciousness The most striking single effect of head trauma is the production of unconsciousness If immediate and transitory, the unconsciousness is due to cerebral concussion If unconsciousness is prolonged it is indicative of contusion or laceration of brain tissue with or without intracranial hemorrhage An intracranial hematoma (see pp 45–48) is the most likely explanation of unconsciousness developing some time after the injury is inflicted

Restlessness

If the patient is restless he should be given 3 to 5 grains (0 2 to 0 3 gm) of *sodium phenobarbital* intramuscularly or intravenously, *paraldehyde,* 2 to 3 drachms (8 to 12 cc) per rectum, *codeine,* ½ grain (0 032 gm), or occasionally small doses of *morphine* hypodermically (not more than ⅛ grain or 0 008 gm) The last usually has distinct disadvantages in the treatment of patients with gross injury to the brain, due to its depressing effect on the respiratory mechanism, and is usually contraindicated

The Scalp

Lacerations of the scalp should be treated as early as possible, but control of hemorrhage, together with application of vaseline and a gauze dressing, is about all that can be done at the first-aid station Early disinfection and suture of scalp wounds are to be desired, preferably within twelve hours Delayed repair of lacerations of the scalp is justified only by necessity The scalp should be shaved for about 3 inches (7 or 8 cm) equidistant from all parts of the laceration Iodine and alcohol are used to disinfect the surrounding scalp and this area infiltrated with 1 per cent *procaine solution* to which has

been added 3 drops of *epinephrine* 1 1000 to the ounce (30 cc.) of solution. Local anesthesia with or without sedatives is preferred in all operations for head trauma. If the patient is restless and can not be controlled with simpler drugs it may be necessary to supplement the local anesthesia with *rectal tribromethyl alcohol* in amylene hydrate (avertin) which is preferred to ether because of the tendency of inhalation anesthesia to raise intracranial tension. Mechanical disinfection of the scalp wound is far superior to chemical sterilization, but *sulfanilamide* or *sulfathiazole powder* should be used in the wound freely as they have been shown to have an extremely beneficial effect.* Large quantities of sodium chloride or Ringer's solution are used to cleanse the laceration. The edges of the contused laceration should be excised for a distance of about ⅛ inch (less than 0.5 cm.) and all underlying macerated tissue such as will be found in the temporal and occipital regions, removed. The wound is again freely irrigated and the scalp closed in two layers with fine interrupted silk sutures for the galea and skin. Drainage is usually unnecessary

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* See bottoms of pages 15 and 196.

injury, unless in a state of shock, tolerate transportation well and this should be borne in mind so that there is no undue delay in transferring such patients to a station or hospital where complete surgical treatment can be provided. Patients with open wounds of the brain do not tolerate air transportation at high altitudes well (see also p. 9).

MANAGEMENT AT STATIONS FOR DEFINITIVE TREATMENT

Diagnosis and General Care

As soon as the patient's general condition permits, a careful study of the effects of the injury should be made. This study is essential to the management of patients with closed as well as open head injuries. The presence or absence of shock should be determined by repeated blood pressure readings and treatment instituted if shock is present. Shock will probably not be a factor after twelve to twenty-four hours from the time of injury (see also p. 15). The state of consciousness should be determined. As long as the patient's state of consciousness is only slightly disturbed and he can be easily aroused by stimulation, one feels that he is withstanding at least fairly well the primary effects of his brain injury. A most careful search for associated injuries must be made. The association of fracture of the cervical portion of the spinal column with trauma to the head and injury to the upper part of the arm or shoulder girdle is frequent and should be kept in mind in the transportation and subsequent investigation in these cases. Roentgenologic examination of the cervical spine should be routine in cases of combined head and shoulder injuries.

Temperature, Pulse, and Respiration

A careful record of temperature, pulse, and respiration in acute head injury is of greatest importance to indicate not only the severity of the injury but the progress of the patient. *Temperature* of 102° F or less indicates a moderately severe injury. Temperature of more than 103° F is indicative of a severe lesion, usually with widespread damage to brain tissue. Fluctuating temperature is often found in injuries of the brain stem.

A slow *pulse* indicates that the patient's compensation for his brain injury is adequate. A rate of 50 to 60 beats per minute is not uncommon for some time after simple concussion. Elevated intracranial pressure may cause increased pulse rate when the limits of compensation have been reached and with the increasing pulse rate there is a fall in blood pressure, indicating that medullary structures have been seriously impaired.

A *respiratory rate* of 10 to 12 per minute is not necessarily significant of danger provided the pulse rate is not unduly low and the patient's state of consciousness is not being progressively impaired. Intracranial clot often causes a progressive decrease in pulse and respiratory rate with deepening stupor and other signs indicating severe compression. Rapid, noisy irregular respiration usually indicates a fatal termination.

Neurologic Study

Pupillary Changes.—Study of the eyegrounds in acute head injury is of little value but repeated examination of the pupils may furnish important information with reference to the diagnosis of intracranial clots. Immediate dilatation of one pupil may be caused by fracture of the base of the skull with injury to the third cranial nerve. Later dilatation may be associated with an intracranial clot which is more frequently on the side of the dilated pupil. The use of mydriatic drugs in cases of acute head injury not only is of no value but will prevent the making of most important observations relating to pupillary changes. To determine pupillary changes promptly, examinations should be made frequently as long as the patient's condition is in doubt. Fixed and dilated pupils almost invariably indicate a fatal termination.

Aphasia, Weakness, Paralysis Reflex Changes.—The neurologic examination should determine, if possible, evidence of aphasia, weakness or paralysis of the face or extremities, reflex changes, and the presence or absence of pathologic reflexes. Patients who have aphasia often give the impression of being more deeply unconscious than they actually are. It is usually a simple matter to determine whether aphasia is present. Such a patient is likely to have weakness of the right arm, and painful stimulation of aphasic patients usually will cause movement of the left arm, exclusively in efforts at protection. Severe lesions of the brain stem frequently show in addition to continued profound unconsciousness, signs of bilateral involvement, such as spasticity of the legs and a bilateral Babinski sign. There may be waves of spasticity in which the patient assumes, with considerable force, postures of decerebrate rigidity

Convulsions.—General or jacksonian convulsions sometimes occur in acute head injury the latter being more common in depressed fractures over the motor area. Convulsions may be controlled with 3 to 5 grains (0.2 to 0.3 gm.) of *sodium phenobarbital* injected intramuscularly or with *paraldehyde* 2 to 3 drachms (8 to 12 gm.) adminis-

tered per rectum Occasionally, inhalations of *ether* may be necessary to control continued frequent seizures

Bleeding or Escape of Cerebrospinal Fluid—Bleeding, or the escape of cerebrospinal fluid, from the ear is evidence of laceration of the dura by a fracture of the base of the skull. In severe bursting fractures in this region there may be escape of brain tissue through the auditory canal In such cases the patients nearly always die Bleeding from the *nose* is significant of fracture of the base of the skull, if it is not due to local injury. The escape of cerebrospinal fluid from the nose after hemorrhage is proof of an opening into the meningeal spaces caused by basal fracture When evidence points to an opening of the meninges by fracture of the base of the skull, *sulfanilamide* or one of its derivatives should be given promptly Hemorrhage from the *ear* is rarely profuse, and no treatment is required except cleansing of the external canal and auricle with alcohol and covering of the ear with a sterile dressing Not infrequently there is a collection of blood in the middle ear, and this may become infected, giving rise to otitis media and mastoiditis. In the presence of a compound fracture through the petrous portion of the temporal bone, the development of otitis media or mastoiditis places the patient in great danger of meningitis

In bleeding or leaking of cerebrospinal fluid from the *nose,* local applications to the nasal passages, packing, and intranasal douches used in an effort to prevent infection in cases of fracture of the base are not only futile but harmful. The development of meningitis will depend almost entirely on whether or not the fractured sinus through which the fluid is escaping is infected, although the prognosis in this respect has been greatly improved by chemotherapy

Lumbar Puncture—This has been widely used in diagnosis and treatment of head injuries The main purpose of lumbar puncture in the diagnosis is to determine the degree of intracranial pressure and whether or not there is blood in the cerebrospinal fluid. It is of no value in determining the pressure unless the pressure is measured with a manometer The Ayer water manometer is most useful for this purpose The severity of the intracranial lesion, however, cannot always be stated in terms of intracranial pressure Many patients with the most severe injuries have a normal or even subnormal pressure, whereas others whose clinical condition shows progressive improvement may have persistent elevation of intracranial pressure Bloody spinal fluid denotes an intracranial lesion, but the evidence of such a lesion usually can be determined by clinical study of the patient. Lumbar puncture in the management of head injuries

is useful perhaps in 15 per cent of cases, to supplement clinical study and treatment. It is advocated for diagnosis as soon as symptoms of shock have disappeared. The indications for later treatment and the period of rest are largely conditioned by the intracranial pressure, the presence or absence of blood in the subarachnoid spaces and, most important of all, by the clinical study of the patient.

Paralyses of Cranial Nerves.—These are not uncommon in association with fracture of the base of the skull. Reference has been made to injury of the third cranial nerve and the importance of study of the inequality of the pupils in the early stages of the injury The seventh, sixth and third cranial nerves are the ones most frequently involved in fracture of the base of the skull. Spontaneous recovery is the rule, although there are exceptions. It is important to distinguish facial paralysis of the peripheral type caused by fracture through the petrous portion of the temporal bone from facial paralysis due to contusion of the brain or an intracranial clot.

Battle's Sign

Ecchymosis about the mastoid region or eye, coming on some hours after injury is indicative of fracture of the middle or anterior fossa of the skull, and must not be confused with contusion caused by local trauma. Such ecchymosis about the mastoid region long has been known as "Battle's sign."

Roentgenographic Examination

Roentgenographic examination should be made of all patients with a history of unconsciousness, but such examination should not be done while the patient is in a state of shock or extreme restlessness. Much valuable time is often lost in attempts to get roentgenograms of delirious patients. Roentgenograms are useless unless they are perfect. If they seem essential, at a time when the patient cannot cooperate, he should be quieted by an intravenous injection of *sodium evipal* or *pentothal sodium* (3 grains or 0.2 gm.) If there are no external evidences of fracture, the making of roentgenograms often can be delayed profitably Roentgenograms are of great importance for patients suspected of having extradural hemorrhage, since this condition rarely occurs without a fracture over the trunk of the middle meningeal artery or one of its branches. They are also of value in the study of depressed fractures of the skull. Roentgenographic study of head injuries, except those of the most minor type, should be routine but it should be used with neither exaggeration nor depreciation of its value.

General Management

Closed Injuries—A large majority of head injuries in which there is no open wound do not require operation. The treatment of closed head injuries without depressed fracture and without intracranial hematoma will resolve itself into one of medical management and competent nursing care It is desirable that the patient be kept in quiet surroundings Restlessness, which often accompanies severe head injuries and particularly those in which subarachnoid hemorrhage occurs, may be treated by *phenobarbital* (1½ to 3 grains or 0 1 to 0 2 gm by mouth), *bromides* (20 to 30 grains or 1 3 to 2 gm by mouth or rectum), *chloral hydrate* (20 to 30 grains or 1 3 to 2 gm by mouth or rectum), or, when restlessness is severe, with *paraldehyde* (3 to 6 drachms or 12 to 24 cc by rectum) The last is a very effective sedative agent.

Unconscious Patients—The head of the bed of the unconscious patient may be elevated unless he is in a state of shock or obstruction of the airways is developing because of accumulation of bronchial secretions If there is respiratory difficulty or evidence of pulmonary complications, the foot of the bed should be elevated from 10 to 15 inches (25 to 38 cm) and the patient turned to the lateral prone position. This posture will promote drainage of bronchial secretion and reduce the intracranial tension resulting from cyanosis caused by respiratory obstruction. Secretions accumulating in the oral cavity should be removed with the suction apparatus The foot of the bed may be elevated for from one to two hours, the resulting position can be alternated with the horizontal position in accordance with the necessities of the case

Nutrition of unconscious patients or those with disturbance of deglutition must be maintained by nasal feeding A small tube may be left in place and strapped to the cheek with adhesive tape Necessary medication can be given through the nasal tube Feeding by mouth should not be attempted until the patient can swallow without difficulty There should be no restriction of water Dehydration in the management of acute head injuries fortunately has been almost abandoned.

Subarachnoid Hemorrhage—Patients with subarachnoid hemorrhage, a frequent result of head trauma, often have fever, are irritable, and complain of persistent headache In this type of case, lumbar puncture has its chief field of usefulness Should the measured spinal fluid pressure be elevated, sufficient fluid should be withdrawn to reduce the pressure to half its original level The Queckenstedt

test should *never* be used in the diagnosis or treatment of head injuries.

Cerebral Edema.—Cerebral edema probably is a rather consistent effect of head trauma and may be associated with numerous punctate hemorrhages or with direct injury to brain tissue and intracranial clots of any size It is highly probable that in most cases in which severe symptoms are attributed to edema alone, the condition actually is a combination of edema plus intracranial hemorrhage. Subtemporal decompression very rarely is necessary for the relief of cerebral edema. If high intracranial pressure is not due to hematoma it should be lowered by repeated lumbar puncture—every six hours if necessary Intravenous infusions of 100 cc. of a 50 per cent solution of sucrose also are useful for this purpose. This solution, however has its chief usefulness in the temporary reduction of intracranial pressure while more effective means for permanent control of intracranial tension are under way

Intracranial Hemorrhage.—Patients who have been rendered unconscious by head injury should be kept under observation for at least a few days to determine whether intracranial hemorrhage has been produced. Those who have more severe head injuries probably will require hospitalization for from one to several months, depending on the type of injury and the rapidity of convalescence. Many patients with apparently mild head injuries may suffer from headache and other symptoms of the post traumatic syndrome. The possibility of development of subdural hematoma must be kept in mind, for this condition may be present in some of the patients who are thought to have post traumatic neurosis. Bilateral small bur openings placed over either temporoparietal region or a ventriculogram may be necessary for the making of a precise diagnosis.

Surgical Treatment

The purposes of operation in the treatment of head injuries are (1) to prevent infection, (2) to elevate depressed fractures of the skull, (3) to remove intracranial clots, and (4) to relieve general pressure due to cerebral edema by subtemporal decompression (rarely required)

Prevention of Infection.—Procedures for the prevention of infection are more frequently used than any other operation for head injuries. The treatment of contused lacerations of the scalp has been discussed on page 31. If such treatment has been given at the first aid post, inspection of the wound should be made as soon as prac

General Management

Closed Injuries—A large majority of head injuries in which there is no open wound do not require operation. The treatment of closed head injuries without depressed fracture and without intracranial hematoma will resolve itself into one of medical management and competent nursing care It is desirable that the patient be kept in quiet surroundings Restlessness, which often accompanies severe head injuries and particularly those in which subarachnoid hemorrhage occurs, may be treated by *phenobarbital* (1½ to 3 grains or 0 1 to 0 2 gm by mouth), *bromides* (20 to 30 grains or 1 3 to 2 gm by mouth or rectum), *chloral hydrate* (20 to 30 grains or 1 3 to 2 gm. by mouth or rectum), or, when restlessness is severe, with *paraldehyde* (3 to 6 drachms or 12 to 24 cc by rectum) The last is a very effective sedative agent

Unconscious Patients—The head of the bed of the unconscious patient may be elevated unless he is in a state of shock or obstruction of the airways is developing because of accumulation of bronchial secretions If there is respiratory difficulty or evidence of pulmonary complications, the foot of the bed should be elevated from 10 to 15 inches (25 to 38 cm) and the patient turned to the lateral prone position. This posture will promote drainage of bronchial secretion and reduce the intracranial tension resulting from cyanosis caused by respiratory obstruction Secretions accumulating in the oral cavity should be removed with the suction apparatus The foot of the bed may be elevated for from one to two hours, the resulting position can be alternated with the horizontal position in accordance with the necessities of the case

Nutrition of unconscious patients or those with disturbance of deglutition must be maintained by nasal feeding A small tube may be left in place and strapped to the cheek with adhesive tape Necessary medication can be given through the nasal tube Feeding by mouth should not be attempted until the patient can swallow without difficulty There should be no restriction of water Dehydration in the management of acute head injuries fortunately has been almost abandoned

Subarachnoid Hemorrhage—Patients with subarachnoid hemorrhage, a frequent result of head trauma, often have fever, are irritable, and complain of persistent headache In this type of case, lumbar puncture has its chief field of usefulness Should the measured spinal fluid pressure be elevated, sufficient fluid should be withdrawn to reduce the pressure to half its original level The Queckenstedt

The diffusion of the force of the impact has been reduced by the localized giving way of the skull.

1. Anesthesia.—It is usually possible to carry out surgical procedures for compound depressed fractures, as well as other operations in the treatment of head injuries, with the patient under the influence of *local anesthesia.* For restless patients a combination of rectal tribromethyl alcohol in amylene hydrate (avertin) and local *anesthesia, or avertin* and *ether* may be required. Small doses of morphine may be used after the preparations for operation are well under way

2 The Scalp.—The scalp is prepared by shaving and disinfecting with alcohol and iodine, as previously described for the treatment of scalp lacerations. Chemical disinfection is not used in the wound, which should be cleansed with large quantities of saline solution. The edges of the wound are subjected to thorough débridement and the instruments used for this are discarded. It may be necessary to enlarge the scalp laceration by incisions to obtain good exposure of the underlying fracture. The scalp flaps are spread with self-retaining retractors and the recesses of the wound are again irrigated. The fragments of bone may be locked in such a way as to prevent elevation if a trephine opening first is not made on the edge of the depression, with removal of a small portion of the depressed bone adjacent to the trephine opening. It then is usually possible to elevate the fragments without the employment of much force.

3 The Dura.—After elevation of the fragments, the dura is inspected for laceration. In cases of marked depression of bone fragments, even though dural laceration is not present, the dura may be opened for the purpose of removal of macerated brain tissue and blood clots, if the facilities are good for the carrying out of major operative procedures (see also p. 15) This should be given especial consideration when the fracture overlies the motor area, where damaged brain tissue, if it is allowed to remain, increases the proliferation of scar tissue and the tendency toward convulsions. It should be remembered, however that when the dura is opened, an important barrier to intracranial infection is removed, and unless the surgeon can be reasonably sure the wound has been thoroughly disinfected, it is better to leave the dura intact. If there has been little contamination of the wound and the surgical treatment of the fracture is undertaken within the first ten to twelve hours, the fragments of bone often can be replaced (see also p. 13) in the cranial defect after mechanical disinfection with irrigating solutions. In a few weeks *these fragments* become firmly fixed. All wounds of this character which have been

ticable after the admission of the patient to the hospital If the laceration has not been adequately treated and it appears to be infected, the wound should be treated as any other infected wound The rapidity with which infection develops varies and débridement of some wounds may be successful as late as twenty-four hours or more after injury However, it is highly desirable that lacerations of the scalp be disinfected and closed within twelve hours after injury, whenever possible Emphasis again is made on the importance of prompt and adequate treatment of scalp wounds, inasmuch as these lacerations, even without fracture of the skull, may lead to osteomyelitis, meningitis, or intracranial abscess Moreover, an infected scalp may prevent operative relief of an intracranial complication which may develop later In cases of severe infection of scalp lacerations, even without intracranial complication, the patient's disability is greatly prolonged. The infected scalp laceration should be treated with *sulfanilamide* or *sulfathiazole powder** in addition to the usual dressings for such wounds. One or the other of these drugs likewise should be given by mouth (see also p 9)

Contusion of the scalp may be followed by a large, painful *hematoma* If the overlying scalp has been abraded by the contusion, infection of the hematoma may result. Aspiration in many cases will remove the larger portion of the hematoma If the blood is clotted, evacuation by open incision may be required A pressure bandage will prevent reformation.

Compound Depressed Fractures of Vault—These cases should be divided into two groups, those in which the dura has not been lacerated and those in which laceration of the dura has taken place Obviously, the incidence of serious infection is higher in cases of compound fracture in which dura has been lacerated than in others

WITHOUT DURAL LACERATION—Surgical treatment of compound fractures without dural laceration is designed to prevent infection and to remove fragments of bone which may be exerting localized pressure on the brain. The main purpose of operation is to remove contaminated tissue of the scalp and skull Patients who have compound fractures of the skull without associated injuries are rarely in a state of shock unless the fracture has been produced by violent force, affecting an extensive area of the skull. Depressed fracture in which a relatively small area of the skull is involved has less diffusion of the concussion to remote regions of the brain, therefore, it is not uncommon to encounter patients with depressed fractures, both simple and compound, who are entirely conscious

* See also bottoms of pages 15 and 196

The diffusion of the force of the impact has been reduced by the localized giving way of the skull.

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subjected to complete débridement within twelve hours should be dusted with *sulfanilamide* or *sulfathiazole powder*[*] and then closed without drainage, if the patient can be kept under observation by the surgeon for ten days or two weeks

4 Fracture over Longitudinal Sinus—A problem of considerable magnitude may be created by compound depressed fracture overlying the longitudinal sinus If elevation of the fragments is attempted in these cases, a method should be used in which the fragments are removed en bloc, so that if there has been penetration of the sinus by a spicule of bone, the opening in the sinus may be accessible immediately after removal of the depressed portion Bleeding from this sinus and other large venous sinuses may be controlled by applying a piece of muscle graft to the bleeding point and holding it in position with the tip of the finger until it becomes adherent. Bleeding from a large dural sinus may almost exsanguinate the patient even before the operation is begun, and every effort should be made to control it promptly One or more transfusions of blood may be essential in such cases (see p 49)

WITH DURAL LACERATION—Compound depressed fractures with laceration of the dura embody all the features of depressed fractures without dural laceration plus the vastly increased danger of serious infection. It is a matter of common observation that even if extensive fracture and the extravasation of brain tissue have occurred, the patient often is conscious The patients usually are not in a state of shock, provided that there are no important associated injuries, or severe loss of blood has not occurred It is often possible therefore to operate on them within the first few hours

1. Surgical Principles—The main purpose of operation is prevention of infection and disabling sequelae, and should aim at removal of all devitalized tissue of the scalp, bone, and brain Thorough disinfection of the entire wound is imperative Large quantities of irrigating solution are necessary, and a suction apparatus is almost indispensable As in other types of open wounds, the laceration of the scalp should be thoroughly disinfected and enlarged when necessary for adequate exposure of the fracture In these cases it is as important to perform débridement and to disinfect the laceration of the brain as it is to remove fragments of bone Blood clots and macerated brain tissue should be thoroughly removed down to the surrounding normal brain tissue by irrigation and gentle suction in which a bent glass tube is used as a suction tip

2 Hemostasis—Bleeding vessels can be located by means of the lighted spatula and drawn up into the tip of the suction tube

[*] See also bottoms of pages 15 and 196

for coagulation with the electrosurgical unit. Complete hemostasis in the wound of the brain is essential. Hemorrhage from the bone can be controlled by application of bone wax. Bleeding from the cerebral vessels usually is not profuse in these operations, but the procedure is time-consuming if thorough débridement, disinfection, and careful hemostasis are carried out.

3 Closure of Dura.—A large defect may result from the removal of damaged brain tissue and this should be filled with physiologic saline or Ringer's solution before the dura is closed. *Sulfanilamide powder* may be used outside the dura but its use beneath the dura is inadvisable if an early complete operation has been done. The dura should be sutured tightly with silk, and if the dural edges cannot be approximated, the defect should be repaired with a fascial transplant, which can be obtained from the galea or pericranium.

4 Closure of Scalp.—The scalp is closed in two layers with interrupted fine silk sutures for both the galea and skin. Drainage usually is unnecessary although in some cases a strip of rubber tissue may be placed down to the dura but no form of drainage should be placed through the dura. Gauze strips never should be packed in the brain to control bleeding. Fungus formation and serious infection almost invariably follow such efforts at hemostasis.

5 Chemotherapy—This is an important adjunct of treatment in these cases: the drugs should be given orally or intravenously as soon as the nature of the injury has been ascertained. The skin sutures should be removed on the third day and the postoperative treatment conducted similarly to that of severe head injury without an open wound. Results of treatment of these severe injuries are almost uniformly good if adequate operation is done early

IF SEEN LATE.—What has been said in the foregoing discussion regarding compound fractures of the skull concerns wounds which are seen early: that is, up to twelve hours after the time of infliction. It is possible, in times of stress especially that transportation may be delayed, and that patients will be brought to the hospital for the treatment of their wounds anywhere from twelve hours to two or three days after being injured.

1 Without Dural Penetration.—In such cases, when depressed fractures without dural penetration are present, the fragments should be removed and the wound left partially or wholly open, and packed with vaselined gauze or with gauze over gutta-percha tissue. *Sulfanilamide* or *sulfathiazole powder* should be used locally in the wound. When the wound is clean, with granulation, it can be closed secondarily or pinch grafts can be used.

2. With Dural Penetration.—In depressed fractures with dural penetration, the fragments of bone should be removed, and if there is herniation of soft, infected brain tissue through the dural opening, as there is likely to be, it should be sucked out until normal brain is reached. The cavity is then packed widely open, again with gutta-percha or vaselined gauze next to brain tissue; it is treated exactly as an abscess of the brain

FRONTAL FRACTURES—Fractures of the frontal region in which one or both frontal sinuses are involved may necessitate removal of the mucous membrane of the sinus and packing of the bony cavity with vaselined gauze against the dura. In such cases, however, the dura should always, if possible, be closed tightly. If the sinus fracture is severe and extensive the mucous membrane should be removed, but if sinus injury is slight, it is better to remove only the torn edges of membrane.

Fractures Involving Base of the Skull.—Fracture of the base of the skull may be diagnosed promptly if bleeding from the ears or nose occurs, but the escape of cerebrospinal fluid may not be recognized until the bleeding has ceased

SIGNIFICANCE OF LEAKAGE OF CEREBROSPINAL FLUID—A leak of cerebrospinal fluid is a source of great danger to the patient. It may persist for only a short time after injury and require no surgical treatment. This is perhaps true in most cases, in many of which the true condition is never recognized In persistent leakage of cerebrospinal fluid, when it is believed that the opening in the dura is accessible, an effort should be made to close the dural perforation Lacerations of the dura amenable to surgical repair usually are those adjacent to the *frontal* and *anterior ethmoid sinuses* Fracture through the *sphenoid* is said to occur in 50 per cent of basal fractures, many of which may produce leakage of cerebrospinal fluid through the nose, the source of which leakage is inaccessible It is not always a simple matter to determine before operation whether it is possible to repair a dural laceration which is causing leakage of cerebrospinal fluid. It is perhaps advisable to wait three days in all cases for spontaneous closure of the dural fistula to occur, meanwhile relying on chemotherapy for the prevention of meningitis The general condition of many patients who have leakage of cerebrospinal fluid may be too serious to permit performance of any type of cranial operation for closure of the leak. If there is a fracture of the frontal region extending into the posterior wall of the frontal sinus, it is probable that such a fracture in the majority of cases also extends through the *cribriform plate* of the ethmoid and it is from laceration of the dura

over the ethmoid that the majority of leaks amenable to surgical treatment occur Operation for closure of dural fistula is not required when cerebrospinal fluid leaks from the ear

SIGNIFICANCE OF AIR IN SUBARACHNOID SPACE.—The entrance of air into the subarachnoid space, ventricle or brain tissue is indisputable proof of a communication between the subarachnoid space and one of the bony sinuses. Pneumocephalus can be diagnosed only by roentgenologic examination, and in cases of leakage of cerebrospinal fluid, roentgenologic examination should be repeated to determine whether or not air is present intracranially and if so, whether it is increasing or diminishing. The situation of the collection of air may determine the site of the dural laceration. If there is a compound fracture in the frontal region, with subsequent escape of cerebrospinal fluid for more than three days, search for the dural fistula may be made by exposure of the dura adjacent to the frontal sinus and anterior ethmoid sinuses. The dural perforation should be closed when possible with sutures or sealed with muscle graft. In cases in which there is no fracture defect, a small frontal flap is necessary for exposure of the dural laceration. When a compound depressed frontal fracture is present, access to the dural laceration causing the leak can be obtained through the bone defect.

Intracerebral pneumocephalus is a rare sequel of fracture of the base of the skull with laceration of the dura and subsequent cerebrospinal rhinorrhea. Evacuation of the intracerebral collection of air with closure of the dural defect, usually is required. In some cases pneumocephalus can be eradicated by filling the air cyst with saline solution. A small osteoplastic flap is required for closure of the dural fistula, unless a bone defect resulting from the treatment of a compound fracture already exists.

Intracranial Hemorrhage—There are two general types of intracranial hemorrhage extradural and intradural. Extradural hemorrhage almost invariably results from injury to the middle meningeal artery in rare cases bleeding is into the posterior fossa and is caused by laceration of a venous sinus. Intradural hemorrhage may be subdural, subarachnoid, intracerebral, or intraventricular

EXTRADURAL HEMORRHAGE.—Although extradural hemorrhage is not a frequent result of head trauma, it must be considered a possibility in all cases. The diagnosis is not difficult when the condition is typical, but the condition is often overlooked because proper consideration is not given to the possibility of its occurrence. Extradural hemorrhage practically always is accompanied by a linear fracture of the skull which lacerates the trunk of the middle men-

ingeal artery or one of its branches; therefore roentgenologic study is of great value in the diagnosis when the condition is suspected. Clinically, when the condition is typical, it is characterized by a brief period of unconsciousness followed by recovery, a so-called free interval, and later development of signs of progressive neurologic impairment. The condition usually is rapidly progressive except when the clot is situated high up toward the vertex and, in such cases, symptoms may develop more slowly

1. Symptoms—One of the first symptoms of extradural hematoma is headache This is usually followed by increasing stupor and profound unconsciousness. Other signs may be dilatation of the pupil on the side on which the clot is situated and contralateral weakness of the face and extremities, particularly the arm Extradural hemorrhage is an urgent surgical emergency If the patient becomes profoundly unconscious for several hours before surgical intervention, the mortality rate is high, even though the clot is removed.

2 Diagnosis—The diagnosis in these cases should be made on the basis of the clinical signs caused by an expanding lesion which usually is situated in the lower part of the motor area and spreads in fan shape upward. In cases of suspected extradural hematoma, lumbar puncture never should be performed. If there is presumptive evidence of such a lesion and it is not found by a trephine opening at the site suspected, the other side should be trephined also Increased intracranial pressure usually can be determined by the clinical examination and lumbar puncture may increase the patient's difficulty without providing any help in the diagnosis The diagnosis of extradural hemorrhage may be especially difficult if patients have had no free interval. Exploratory trephine openings made with the patient under the influence of local anesthesia are accompanied by so little risk that they should be used more frequently in the diagnosis of suspected intracranial clots If extradural hematoma is present it will be situated on the side of the fracture, as previously disclosed by roentgenologic examination, and a trephine opening made at the intersection of the superior temporal line with a line across the vertex, connecting the tips of the auricles, on this side usually will expose the clot as soon as the opening in the bone is made

3 Removal of Clot.—No effort should be made to remove any part of the clot until the opening in the bone has been sufficiently enlarged to give adequate exposure of the hematoma, which should be removed by suction. The bleeding vessel is located by use of the lighted spatula which can be used to occlude the vessel while the clot is further removed. When the artery is ruptured near the foramen

spinosum, considerable difficulty may be encountered in finding the bleeding point and it may be necessary to plug the foramen with cotton to control the bleeding. In many cases bleeding from the ruptured vessel has stopped spontaneously, but if this has not occurred the vessel can be coagulated with the electrosurgical unit. It is important to remove the clot rather completely, except for a coagulum from numerous small dural veins which may have been broken in the separation of the dura from the skull by the accumulating blood from the hemorrhage of the ruptured artery In some cases the clot extends almost to the midline of the vault and venous bleeding from the dura, high up near the longitudinal sinus, may be extremely difficult to control. Light packing of the bleeding dura with gauze strips usually is sufficient to stop all *oozing* and may be required in some cases. If expansion of the brain does not follow removal of the clot, it may be well to suture the dura in a number of places to the galea or temporal muscle to prevent reformation of clot in the large dead space. In cases in which condensation of the brain is marked and in which there is little expansion after removal of the clot, convalescence generally is prolonged. The outlook for recovery after prompt removal of extradural hematoma is good, but the mortality rate remains high because of delayed diagnosis.

A few cases of extradural clot in the posterior fossa arising from rupture of a venous sinus have been reported. These cases always include fracture of the skull and give signs of marked compression of the cerebellum. Early operation for removal of the clot, as in middle meningeal hemorrhage is required.

INTRADURAL HEMORRHAGE. 1 Subarachnoid Hemorrhage.—This is the most frequent form of hemorrhage produced by trauma to the head, but it does not require operation. Repeated lumbar puncture may be used to reduce the intracranial pressure and to relieve the headache which often accompanies such lesions. Lumbar puncture should not be employed in these cases until sufficient time has elapsed for the arrest of hemorrhage, which usually occurs after twenty four hours.

2 Acute Subdural Hematoma and Hydroma.—There are two types of subdural hematoma, acute and chronic. The acute type is more frequent than is usually believed, and often is responsible for the elevation of intracranial pressure of patients who do not present distinctive signs of intracranial clot, but who continue to be stuporous or unconscious. It is commonly associated with injury to the brain tissue, and is therefore found in cases in which the blow to the head has been rather severe The mechanical equivalent of

this type of hematoma is a subdural hydroma and they cause similar symptoms Patients who have a subdural collection of blood or bloody cerebrospinal fluid (hydroma) may show improvement shortly after injury only to have signs of increasing compression develop later. The progression of symptoms in these cases is much less rapid than the progression of those of extradural clots Enlargement of the pupil may develop on the side of the clot, with weakness of the extremities on the opposite side The clinical picture, however, is by no means so characteristic as that of middle meningeal hemorrhage

(*a*) Diagnosis —The diagnosis of acute subdural hematoma may be suspected by the clinical course of the patient but verification of the lesion requires bilateral exploratory openings placed at the intersection of the superior temporal line with a line connecting the tips of the auricles, as in surgical exploration for extradural hematoma (p 44)

(*b*) Removal of Clot.—It may be necessary to enlarge the bur opening with rongeurs to give full access to the clot, which usually can be removed by irrigation with saline or Ringer's solution and gentle suction. Convalescence after removal of an acute subdural hematoma may be delayed because of severe associated injury to the brain. If a clot or hydroma is not discovered when exploratory trephine openings are made and the intracranial pressure remains high, subtemporal decompression may be required.

3. Chronic Subdural Hematoma.—An encapsulated collection of blood in the subdural space is known as a "chronic subdural hematoma." The term "chronic" is perhaps more nearly accurate in denoting the time at which the clot is recognized than as descriptive of the pathologic condition The transition of acute subdural hematoma to the chronic type is manifested by the development of a thin, delicate membrane surrounding the clot. This form of intracranial clot is probably always the result of injury to the head, but the injury responsible for the clot may appear to be trivial and show little primary effects

(*a*) Symptoms —Patients who have chronic subdural hematoma often are mentally confused and may fail to recall having received the slight injury which caused the clot. There is sometimes a considerable interval between the injury and the recognition of pressure symptoms, the interval often is weeks or rarely, a few months Headache, however, is almost constant from the time of the injury to the head. Mental changes are characteristic of this lesion, and focal signs, such as inequality of the pupils or weakness of the extremities on one side, often develop General signs of severe cerebral compression

sooner or later make their appearance. If there is a history of injury to the head, however slight, followed by an interval of apparent recovery with subsequent slowly progressive signs of compression, the surgeon should consider the likelihood of chronic subdural hematoma (see also p. 30)

(*b*) Diagnosis.—The condition may be confused with post traumatic syndrome and the injection of air sometimes is required for precise diagnosis. In view of the fact that bilateral trephine openings, placed as previously described, generally will disclose the lesion if one is present, this method of diagnosis in cases of suspected subdural clot is preferred. The diagnosis may be verified and surgical treatment accomplished by this single procedure.

(c) Removal of Clot.—An osteoplastic flap usually is unnecessary for the removal of subdural hematoma. The contents of the sac generally are liquid, although in some cases there may be a large solid portion of clot and, in the latter event, after primary evacuation through a trephine opening, it may be necessary to make an osteoplastic flap. In view of the fact that the condition of many of these patients is extremely serious before the lesion is recognized, a bur opening is preferred to the osteoplastic flap as a primary procedure because the clot may be completely evacuated in this manner in the majority of cases, and the patient thereby spared a major cranial operation.

The clot is encased in a membrane which may be as much as ⅛ inch (0.3 cm.) in thickness on the dural side and of almost transparent thinness where it is in contact with the arachnoid. In the majority of cases the sac overlies a large part of the cortex of one cerebral hemisphere, and in many cases (25 per cent) the lesion is bilateral. Small encapsulated subdural clots sometimes are found in various intracranial situations, indicating that the source of hemorrhage in subdural hematoma may be a ruptured vein traversing any part of the subdural space The usual situation, however is over the cerebral cortex. When the dura is incised over a chronic encysted clot, the diagnosis at once becomes obvious. A dark, greenish black glistening membrane, often with spots of yellow comes into view When the membrane is opened the contents escape under tension. The fluid is very much like rusty venous blood containing small dark particles resembling coffee grounds. The sac should be irrigated through a soft-rubber catheter and removal of the contents will be facilitated by lowering of the patient's head. Multiple trephine openings generally are unnecessary for the removal of a unilateral clot. Unless previous injection of air has disclosed only a single clot,

bilateral surgical exploration always should be done Drainage with a rubber tissue drain or small catheter may be maintained for a few days after operation Prompt expansion of the brain after removal of the clot is a favorable sign Failure of the brain to expand is an indication that the patient's convalescence will be slow and the prognosis uncertain Lowering of the head of the patient may facilitate expansion of the brain

4 Intracerebral Hematoma—Intracerebral hematoma (see also p 30) is not a frequent result of trauma, this being due more often to disease or malformation of the blood vessels However, a collection of blood within the cerebral tissue may be caused by injury With a history of injury followed by signs of general compression, associated with early disturbance of functional areas of the brain, the possibility of intracerebral clot should be considered The injection of air generally is necessary to disclose the situation of the lesion These hematomas, as a rule, can be evacuated through a ventricle needle, once their situation has been ascertained

5 Intraventricular Hemorrhage—Intraventricular hemorrhage usually is caused by disease, but rarely may result from trauma These lesions can be diagnosed only by ventriculography and exploratory operation Intraventricular hemorrhage generally is fatal, but evacuation of the clot may be accomplished, with recovery of the patient, in rare instances

Simple Depressed Fracture—Simple depressed fractures of the skull should be elevated as soon as practicable, but operation never should be done for this fracture while the patient is in a state of shock or in serious general condition from any cause It is doubtful that the continuing depression of fragments of bone is responsible for the late bad results which have been attributed to depressed skull fracture The injury to the brain at the time the fracture was sustained probably is a more important factor in the production of late untoward effects, such as headache and convulsions

SURGICAL PROCEDURE—Simple depressed fractures can be elevated with the patient under the influence of *local anesthesia,* exposure being accomplished through a curved scalp incision Hemorrhage is controlled by finger pressure and application of forceps to the galea The incision should be spread by self-retaining retractors Elevation of the depressed bone, as a rule, requires that a preliminary bur opening be placed near the edge of the depression Through this bur opening an elevator can be passed and with leverage the fragments can be raised As a rule, however, removal of a portion of the depressed bone with rongeurs is required before the fragments

of bone can be unlocked and removed. The dura may be lacerated and there may be extravasation of brain tissue beneath the scalp However, the danger of infection in such a case is negligible. Macerated brain tissue should be removed by gentle suction and hemostasis accomplished by coagulation of the bleeding vessels. When marked depression of bone occurs and the appearance of the dura indicates bleeding beneath, even though the dura has not been torn, it may be assumed that there have been laceration and contusion of the brain tissue. In such cases the dura should be opened for inspection of the cortex and for removal of the severely damaged brain tissue, if such is present. The removal of macerated brain tissue and clots permits healing of the wound in the brain with less formation of scar tissue and diminishes the tendency toward the development of post traumatic convulsions. The dura should be closed tightly and the fragments of bone replaced. The wound in the scalp is closed without drainage. The fragment will become firm within a few weeks.

Fracture over Longitudinal Sinus.—It may be advisable to disregard small simple depressed fractures over the longitudinal sinus when the depression is slight, in view of the fact that the complication of hemorrhage arising from penetration of the sinus may present a formidable operative problem. Moreover small fragments of depressed bone in this situation probably do not injure the cortex and will not produce the sequelae which have been attributed to the larger depressed fractures over the cerebral hemispheres (see p. 40)

Subtemporal Decompression for Cerebral Edema.—Subtemporal decompression for the relief of intracranial pressure resulting from trauma to the head is rarely required, certainly in not more than 1 or 2 per cent of cases. The operation is done with the patient under the influence of *local anesthesia* supplemented by *sedative agents* as previously described. Subtemporal decompression may be done for patients who remain unconscious for a few days, with persistent elevation of the pressure of the cerebrospinal fluid, when exploratory bur openings in the lower parietal region on each side have disclosed no subdural hematoma or hydroma. When the incisions for exploratory bur openings are made, the outline of an incision for subtemporal decompression on the right side also should be made by scratching the scalp with the point of a knife, in a straight line down to the zygoma. When subtemporal decompression is being carried out, the attachment of the temporal muscle and fascia should not be disturbed. Therefore, an area of bone will separate the exploratory

trephine opening from the bone defect made for the decompression The incision through the muscle and scalp is spread with a self-retaining retractor and an area of bone about 2¾ to 3 inches (about 7 5 cm.) in diameter should be removed as close to the base of the skull as possible The dura is opened with stellate incisions If the tension is very high, silk sutures should be placed in the muscles before the dura is opened, their ends clamped, and the sutures retracted from the field Exploration of the temporal lobe may be carried out with a ventricle needle. The muscle sutures are then tied. Closure of the fascia is unnecessary when subtemporal decompression is done for trauma The scalp is closed in two layers in the usual manner

CHAPTER II

GUNSHOT AND OTHER INJURIES OF SPINAL CORD

CLAUDE C. COLEMAN M.D., and COBB PILCHER, M.D

INJURIES of the spinal cord not due to missiles which strike the cord usually are caused by fracture-dislocation of the spinal column. A large number of such injuries in civil life occur as a result of in dustrial and transportation accidents. Similar injuries in warfare inevitably result from the extensive use of mechanized equipment and the aerial bombing of cities and towns of belligerent countries. Wounds of the spinal column naturally are divided into two groups (1) wounds which produce fracture of the spinal column without injury to the spinal cord and (2) wounds which involve the spinal canal, with injury of the spinal cord. Many factors in the treatment of the two groups are identical, and they will be considered together for the most part.

TRANSPORTATION

The management of a patient who has a spinal injury should begin at the scene of trauma. Patients who have a severe injury of the spinal cord often volunteer the information that the injury caused immediate loss of use or numbness of the lower extremities, or they may complain of local pain in some region of the spinal column. In either case the information indicates at once the necessity for great care in the moving of such patients. Such care is more im portant in spinal injuries than in those of any other part of the body

The transportation of the patient to the first-aid post or hospital should be so planned as to prevent unnecessary handling or transfer from one carrier to another and to avoid twisting or bending of the spinal column in any way Injury to the spinal cord may be caused, or if present it may be increased, by the slipping of a frac tured vertebra because of improper handling or transportation. Permanent paralysis may result in cases in which the original injury otherwise might have been curable.

The patient should be lifted by two or more people, with the entire length of the spinal column supported and maintained as nearly straight as possible. Patients who have *injuries in the thoracic* or lumbar portion of the spinal column should be transported in the *prone position* but, since the type of fracture cannot be ascertained immediately, it is better to transport them in the position in which they are found to avoid further injury while they are being turned The *supine position* is better for those who have injuries of the cervical part of the spinal column, with immobilization of the head achieved when practicable by the use of sandbags If recognizable kyphos exists, a small, soft pad (such as a folded sheet or coat) should be placed directly under the deformity

Time is of greatest importance in the care of injuries of the spinal cord and all possible speed should be employed in the evacuation of patients to a station where definitive treatment can be carried out.

SHOCK

The injury to the spinal cord may be associated with important injuries in other parts of the body, and the patient may be in a state of severe shock arising from a combination of the injuries and exposure to which he has been subjected The patient who is in a state of shock should be wrapped warmly and transported promptly to the first-aid post or to a convenient hospital as soon as possible

Patients in shock will exhibit pallor, profuse perspiration, extreme weakness, rapid, feeble pulse, and low blood pressure

If shock is present, as determined by a systolic blood pressure of less than 100 mm of mercury, nothing more than a brief survey should be made of the patient's injuries until the patient has recovered from shock. This survey should include a search for the gross evidence of spinal as well as associated injuries

Treatment

Treatment of shock should be given first consideration. This should include warmth, lowering of the head, giving of morphine, the oral, subcutaneous, or intravenous administration of fluids, and the early transfusion of blood or intravenous infusion of plasma or serum Shock of the neurogenic type, without excessive hemorrhage or loss of tissue fluids, often will respond to quiet, warmth, and absence of manipulation without the employment of more heroic measures

RECORDS, BEGINNING WITH FIRST AID

When the patient has been brought for first-aid care, a brief record should be made in which the date and approximate time of injury, date and time of examination, and results of preliminary examination are listed. It is most important that all observations made in the primary examination be recorded in detail, and that they accompany the patient, so that these may be used for comparison with observations made in subsequent examinations. On the keeping of careful records of patients depends not only the individual's welfare, or even his life but also the possibility of improvement of methods of therapy through study of results in large numbers of cases. Every procedure, every important medication, and every significant change in a patient's condition should be briefly but clearly added to the original observations in the case.

PRELIMINARY CARE OF WOUND AND CONTROL OF HEMORRHAGE

Operative treatment of spinal wounds should not be attempted until facilities and time are available for complete laminectomy because unexpected findings may make such an operation necessary and incomplete operation may do more harm than good.

At advanced stations, cleansing of the skin with soap and water removal of superficial and loose foreign bodies, fragments of bone, and blood clot should be followed by the use of *sulfonamides* locally and by mouth, the application of a sterile dressing, and rapid evacuation to the rear External hemorrhage should be controlled by the application of a pressure bandage or by such other means as may be required by the circumstances of the case. Hemorrhage in large wounds is best controlled by packing with sterile vaselined gauze. In massive wounds, the spinal cord may be exposed in the depths of the wound and great care must be employed to avoid trauma to or compression of it.

MEDICATION

Analgesic Drugs

Patients who have spinal injuries often suffer from excruciating pain in nerve roots. *Morphine sulfate* should be given without hesitation in dosage (0.016 gm., or 1/4 grain) sufficient to bring relief of this pain. The date and time of administration and the amount of all medication given should, of course, be entered on the man's field medical card.

Antitetanic Medication

If men have not been inoculated previously with tetanus toxoid, antitoxin should be given as early as possible, as is described in Chapter I, the dosage and date of administration to be recorded on the field card as usual.

Sulfanilamide or Sulfathiazole

These preparations should be administered in initial dosage of 4 gm (60 grains) and recorded

EARLY CARE OF BLADDER

If the patient is unable to void (and this is almost always the case), a careful *attempt should be made to express urine by the* manual exertion of fairly heavy pressure on the distended bladder, above the symphysis pubis As a rule, this can be done without undue difficulty after a little practice, and rather complete emptying can be secured thereby

If manual expression does not succeed, an inlying catheter should be placed immediately This catheter should, if possible, be attached to a Y tube which can be clamped off One branch of this tube should lead to a bottle for the reception of urine, the other should lead to a bottle which contains a mildly antiseptic solution for periodic irrigation of the bladder. If the second bottle cannot be handled well during transportation when it contains solution, it should be kept attached but empty, sterile, and stoppered, so that solution may be put into it from time to time and the bladder irrigated. Patients who carry indwelling catheters should be given *sulfathiazole,* 7½ grains (approximately 0 5 gm) twice daily as a prophylactic measure. The bladder should be irrigated once every two days and the catheter changed weekly

DIAGNOSTIC STUDY

When the patient reaches a hospital in which complete treatment can be carried out, *he should be allowed to recover from shock* if shock is present. If shock is absent, or after he has recovered from shock, he should be examined as thoroughly as facilities permit, so that the presence or absence of injury to the cord and the type of therapy to be employed can be determined

If the patient is conscious it should be determined on the basis of his statement, if possible, whether or not paralysis began immedi-

ately Inspection of the region about the spinal column often will reveal that contusion and edema overlie the fracture, and kyphosis frequently is seen in this region. Examination should include tests for motor power of the extremities, condition of the reflexes, sensory changes, and the determination of the neurologic level of the lesion. The presence or absence of deep pressure sense in the calves of the legs and proprioceptive disturbance in the toes should be noted. The condition of the bladder in the presence or absence of retention should be determined.

Roentgenologic Examination

Roentgenograms of the spinal column at the level of the suspected fracture should be made as part of the routine examination, to determine the extent of the injury to bone, the presence of foreign bodies and impingement on the spinal canal. Great care must be exercised in turning the patient for the making of different views, lest spinal deformities be increased and further damage done to the cord.

The association of injury to the head, shoulder girdle, and cervical part of the spinal column is so frequent that all patients who have injury to the head and shoulder girdle should have the benefit of routine roentgenologic examination of the cervical portion of the spinal column so that injury in that region can be excluded or confirmed.

Neurologic Examination

If the spinal cord has been injured, the patient will present impairment or loss of the motor and sensory functions below the level at which the injury has occurred, and usually he will be unable to empty the bladder Accurate localization of the injury usually is best determined by the upper level of sensory impairment (Figs. 11, 12) A progressive rise in this level often indicates intraspinal hemorrhage with extension of the hematoma upward. It should be remembered that the sensory segments of the skin correspond to segments of the spinal cord whose position in the spinal canal is one or two vertebrae higher than the dermatomes involved.

The neurologic level usually coincides with the site of injury to the bone, in fracture-dislocation of the spinal column with involvement of the cord.

It is likewise important to determine the depth of sensory loss that is, to learn whether there is any response to a severe type of pain arising below the level of the lesion of the cord.

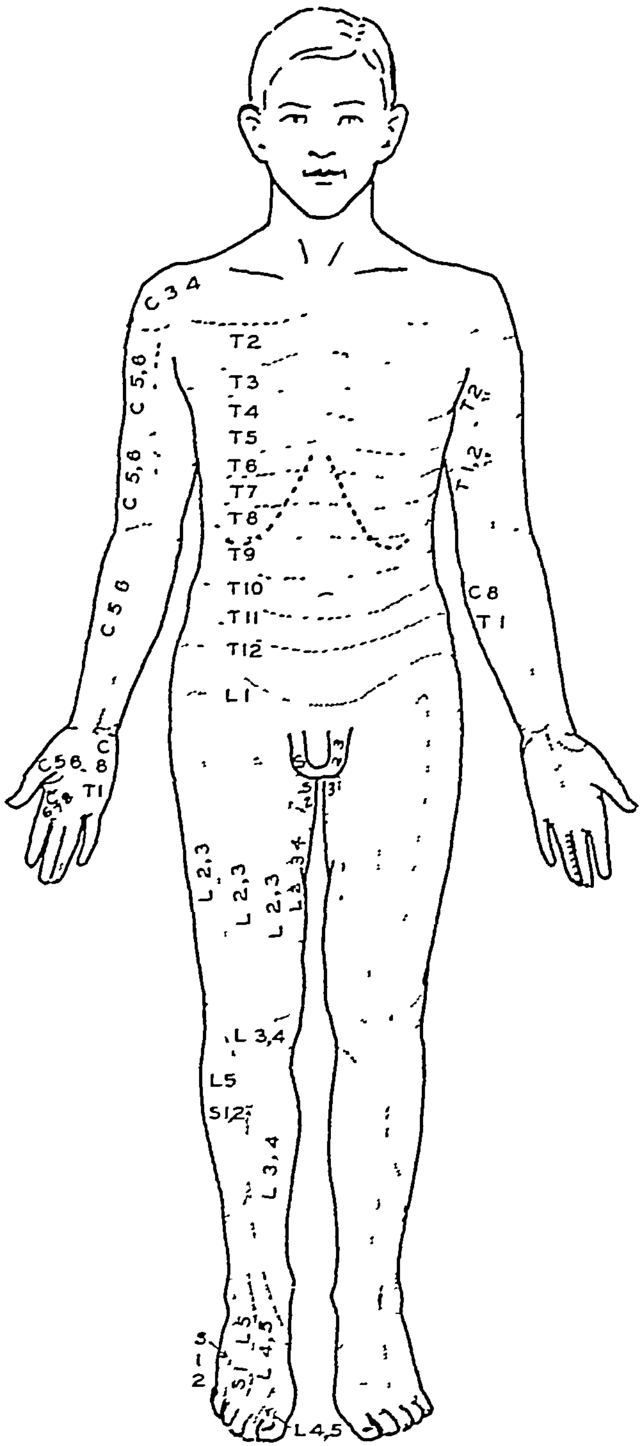

FIG. 11 —Segmental distribution of cutaneous nerves anterior view

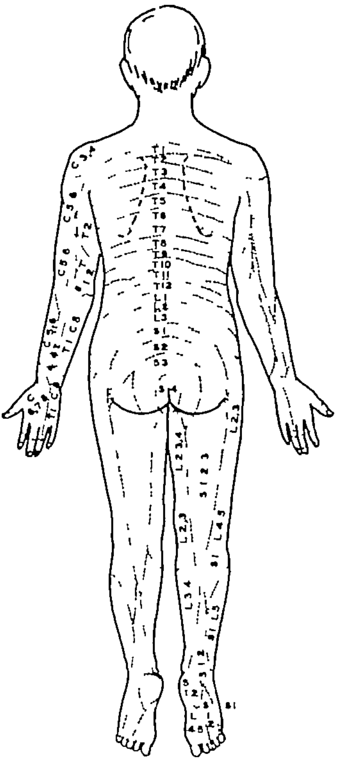

Fig. 12.—Segmental distribution of cutaneous nerves, posterior view

From the point of view of prognosis, complete distinction should be made between lesions of the spinal cord and those of the cauda equina.

Queckenstedt Test and Supplementary Measures

The Queckenstedt test should be carried out if signs of involvement of the cord are present. This is done by lumbar puncture, with the patient lying on his side. The spinal needle is connected with a manometer and the initial pressure is observed The jugular and other veins are then obstructed by firm pressure exerted around the neck on both sides If block exists, a corresponding increase in pressure of the spinal fluid will not occur A slow, intermittent increase in pressure indicates that almost complete block is present A record of this test should show (1) the initial pressure of the spinal fluid, (2) the rapidity of increase and decrease of the column of fluid in the manometer when the jugular veins were compressed, (3) the presence or absence of gross blood in the spinal fluid, and (4) the pressure after a recorded quantity of spinal fluid was removed More than one fracture may be present in the spinal column at different levels Roentgenograms often do not indicate whether or not pressure is being exerted on the cord and this fact must be determined by the Queckenstedt test.

To supplement the Queckenstedt test, when there is evidence of subarachnoid block, 5 to 10 cc of air may be injected through the needle that was employed for lumbar puncture and the upper part of the body elevated. If obstruction is incomplete the patient in a few seconds will complain of headache, whereas if block of the spinal subarachnoid space at the level of the injury is complete, headache will not follow, but the patient may complain of root pain arising just below the segmental level of the compression

In severe injury of the spinal cord, even though initial results of the Queckenstedt test disclose incomplete block, swelling of the cord from contusion may occur subsequently, and produce complete obstruction and compression of the cord It is often advisable that the Queckenstedt test be repeated once or more, at daily intervals, so that pressure on the cord may be recognized and relieved by prompt laminectomy

Instantaneous Loss of Function

The severity of injury to the spinal cord may vary greatly, but usually, the type of injury caused by fracture-dislocation is likely to be very severe, often causing complete physiologic interruption In

cases in which the cord is crushed by dislocation of the vertebra, the loss of function below the level of the lesion is instantaneous and complete. Patients retaining consciousness throughout are able to supply information as to the instantaneous loss of function of the spinal cord. The importance of this will appear later

Recoil of Displaced Vertebra, Concussion and Mild Injury

Recoil of the displaced vertebra, which is sometimes sufficient to achieve normal alinement, is not uncommon in fracture-dislocation of the spinal column. The greatest displacement continues only so long as the displacing force is in action, and the damage to the cord generally is completed by the time dislocation has reached its maximum. After partial or complete recoil of the displaced vertebra, bony pressure is reduced and may in some cases be completely removed from the injured cord. Roentgenologic examination after recoil can give no information as to the extent of displacement at its maximum therefore, the gravity of the lesion must be determined by the patient's history and the evidence of impairment of function of the cord below the level of the lesion.

Concussion and *mild injury* may cause changes in reflexes, weakness of the extremities, temporary disturbance of vesical function, and root pain. *Contusion* of the cord with intramedullary hemorrhage may be indicated by the presence of the Brown-Séquard syndrome.

Crushing of Cord

It is often stated that because of spinal concussion and spinal shock resulting from trauma, it is impossible accurately to distinguish between complete instantaneous physiologic interruption, in which recovery to some extent may occur later and a total transverse anatomic lesion, the effects of which are permanent. Concussion is a factor of importance in injury to the cord caused by projectiles and it may be a factor although to a less degree, in other injuries resulting from a direct blow over the spinal column. In cases of fracture-dislocation arising from indirect violence, however which is the usual method of production of injuries to the cord, a better explanation than spinal shock or concussion for immediate loss of function is the crushing of the cord by the displaced vertebrae.

Other Injuries

It is of great importance to remember that missiles which have penetrated the spinal column also may have entered or passed through the neck, thorax, or abdomen. Careful examination for in-

juries in these regions must be made and the observations considered in formulating the decision as to the course of therapy

TREATMENT IN ABSENCE OF DURAL PENETRATION OR INJURY OF SPINAL CORD IN GENERAL

Wounds from Single Missiles

If wounds produced by the penetration of single small missiles are seen early (within twelve hours) they may frequently be closed without drainage after excision of damaged skin and superficial tissues, even though fractures may exist and the missiles may be retained If the injury occurred more than twelve hours previous to the time when the patient is first seen or if obvious infection exists, wide incision should be carried out and foreign bodies and free fragments of bone removed Such wounds should be drained or packed open with vaselined gauze or with gutta-percha placed next to the raw surface and gauze placed over the gutta-percha In all cases the local and systemic use of *sulfonamides* is of great importance

Extensive Wounds

More extensive wounds, with shattering fractures, wide damage to tissues, multiple foreign bodies, dirt, fragments of clothing, and the like, should be radically treated After preparation of the skin with soap and water and a suitable antiseptic solution, the wound should be thoroughly irrigated with sterile water or saline solution and wide débridement carried out. All damaged tissue, foreign material, and free fragments of bone should be removed Laceration or contusion of the dura must be carefully avoided The choice among closure, drainage, or open packing must depend on the time element and the appearance of the wound

TREATMENT IN PRESENCE OF INJURY TO SPINAL CORD IN GENERAL

Aim of Treatment

Injuries of the spinal cord are among the most discouraging lesions in all the field of surgery Any acute injury, whether it is laceration, contusion, or rapid compression, produces devastating paralysis and anesthesia from which recovery is the exception, rather than the rule Nerve cells and nerve fibers of the spinal cord which are destroyed never regenerate It is therefore apparent that lacerations or contusions of the cord cannot be ameliorated by any opera-

tive procedure and that the sole neurologic benefit to be obtained from operation must come from relief of compression of a cord the fibers and cells of which have been compressed but not destroyed.

Operations are aimed at (1) débridement and closure, as already described, and (2) decompression of the cord, if compression exists.

Decision to Employ Any Surgical Measures

If the patient has remained conscious throughout and states that with the impact of injury he became paralyzed and lost all sensation in the lower extremities, and if the examination shows absence of the Babinski reflex, deep sensibility tactile sensation, and deep reflexes distal to the lesion or in other words, if complete physiologic interruption is present, experience indicates that the situation is hopeless, regardless of the treatment employed. The only recovery which can be expected in such cases is some degree of return of segmental innervation just below the level of the injury Lesions of the cord caused by fracture-dislocation rarely are progressive although they may become so by injudicious handling of the patient. Experience shows that the maximal damage to the cord usually is manifest immediately, and if the cord has not been crushed, considerable recovery which will extend over a long period may be expected. The inherent tendency after a partial lesion, for recovery of much of the function temporarily lost, probably deserves a large share of the credit for improvement commonly attributed to operation or manipulative procedures designed to decompress the canal or restore the alinement of the vertebral column.

Indications for Decompression.—Presumptive evidence of compression of the spinal cord sufficient to call for decompression may be adduced if one or more of the following observations is made

1. Incomplete paralysis and anesthesia below the anatomic level of the injury
2. Roentgenologic evidence of impingement of bone or a foreign body on the spinal canal.
3. Blockage of cerebrospinal fluid or partial block among patients who display evidence of incomplete section of the cord.
4. Upward progression of the level of neurologic impairment, which usually is the result of hemorrhage into the canal or within the cord. Extensive extradural hemorrhage is extremely rare.

Intolerable pain is a factor to be taken into account when the question of operation is under consideration.

Still another factor namely the time which has elapsed after

injury, enters into the indications for decompression Nerve tracts functionally "blocked" by compression for as long as forty-eight hours never will regain function and in such circumstances decompression no longer is indicated. Also dependent on the time element is the likelihood of inciting or spreading of infection in the meningeal spaces by extensive operation. Definite infection of the wound is a contraindication to further opening of the meninges Concerning cases in which the condition is borderline no arbitrary rule can be stated and the surgeon's judgment plus the urgency of treatment of other patients whose condition is more definitely remediable must be the deciding factors

Decision to Employ Laminectomy

A most important decision which has to be made in the management of acute injury to the spinal cord is whether or not laminectomy should be done Laminectomy in fracture-dislocation with injury to the spinal cord is indicated only for the relief of localized compression of the cord when the cord has not been divided or hopelessly crushed at the level of the injury Presence of compression of the cord can be determined accurately only by the Queckenstedt test. If the result of the test is negative there is no indication for operation in the presence of closed injuries, regardless of the severity of the lesion If the result of the Queckenstedt test shows that obstruction of the spinal subarachnoid space is present, laminectomy is indicated only if the surgeon has reason to believe that the cord may regain function of some degree

Wide dislocation of the vertebral segments usually destroys the cord at the level of the dislocation and, obviously, patients who have such an injury should not be operated on even though the result of the Queckenstedt test is positive The indication for laminectomy as offered by the result of the Queckenstedt test also may have to be set aside in certain cases in which other associated circumstances show that the bony injury has produced a crushing injury of the cord. Experience demonstrates that complete and instantaneous physiologic interruption of the function of the spinal cord after fracture-dislocation is permanent, regardless of the treatment employed.

If there is any doubt, however, that complete loss of function was instantaneous (and this doubt may be raised because of the state of consciousness of the patient at the time of the injury) laminectomy should be done if the result of the Queckenstedt test is positive

Treatment for Injury of Particular Regions in Presence or Absence of Injury to Spinal Cord

Patients who require treatment by manipulation or traction should be evacuated as rapidly as possible to permanent hospitals in the interior where facilities of this kind can be provided.

Cervical Injuries

Skeletal Traction versus Laminectomy—Fracture-dislocation in the cervical part of the spinal cord in which immediate and complete physiologic interruption occurs should be reduced by skeletal traction exerted on the skull. In such cases the outlook for recovery of function is practically hopeless, but whatever benefit might be secured from laminectomy can be secured by the much more simple method of skeletal traction, which can be applied in a few minutes without greatly disturbing the patient. There appears to be no indication for laminectomy in such cases.

If the cervical injury has not completely destroyed the function of the cord peripheral to the injury the dislocation, if one is demonstrated by roentgenologic examination, should be reduced by skeletal traction. Reduction of the dislocation may promptly relieve obstruction of the spinal subarachnoid space, but in many cases the result of the Queckenstedt test may remain positive for several days, at least.

Injuries in the cervical portion of the cord, both complete and incomplete, may be produced by recoiling dislocations, with little evidence of bony injury as demonstrated by roentgenologic examination. If the patient's history and results of examination show that the lesion was immediately complete, operation is not indicated. If the lesion is partial but progressive, in spite of traction, laminectomy should be done if obstruction of the spinal subarachnoid space can be demonstrated by the Queckenstedt test.

Fracture-dislocation in the cervical part of the spinal column without injury to the cord may produce disturbing root pains and seriously interfere with mobility in the cervical region. In such cases dislocation should be reduced by skeletal traction. This method is preferred for the reduction of fracture-dislocation in the cervical region to manual reduction, for it is not accompanied by the risk of further damage to the cord.

Application of Skeletal Traction—Crutchfield tongs are used for the application of skeletal traction, and reduction of the dislocation sometimes is obtained by this method within a few minutes after

the application of weights To apply the skull tongs a strip of scalp 3 inches (7 5 cm) wide across the vertex is shaved and disinfected With the patient under the influence of local anesthesia, two stab wounds are made in the scalp on a line with the mastoid processes, equidistant from the midline A small drill point equipped with a guard to prevent penetration to more than a depth of 4 mm is inserted in the incisions in the scalp and the bone is penetrated. The points of the tongs are inserted in these openings and are held firmly by the setscrews which are tightened sufficiently to hold the tongs in place, even when a force of 25 to 30 pounds (about 11 to 14 kg) is exerted A fixed guard is placed on the tong to prevent further penetration It may be necessary to tighten the tongs every few days if prolonged traction is required. The advantages of this method are its simplicity and effectiveness in the reduction of cervical dislocations, moreover, the type of apparatus used permits the patient to be turned from side to side in routine nursing care, while the traction is being maintained

Thoracic Injuries

The same general indications for laminectomy for injuries in the cervical region of the spinal column are applicable to injuries in the thoracic portion of the spinal column. Methods of treatment involving hyperextension do not restore alinement in the thoracic region as they do in the thoracolumbar or lumbar portion The practicability of hyperextension should be determined by the orthopedists

Lumbar Injuries

Many fractures of the spinal column are accompanied by compression of the bodies of vertebrae Hyperextension may be very effective in restoring alinement and relieving pressure on the cord in such cases Laminectomy should be carried out if pressure on the lower part of the cord or on the cauda equina continues after hyperextension has been done, or if a lesion which has been causing mild symptoms becomes progressive and if the result of the Queckenstedt test is positive Lesions in the lumbar part of the spinal column at any level respond very favorably to hyperextension methods If the injury to the cauda equina is very severe, and hyperextension does not relieve block of the subarachnoid space, open operation is indicated for relief of pressure, and it should be done promptly

Caudal Injuries

A lesion of the cauda equina should not be placed in the same category as a lesion of the cord. If there is marked dislocation of

the lumbar vertebrae it may be possible to remove the pressure by manipulation and operative measures, with a reasonable hope of improvement in function of the injured roots of the cauda equina. Regeneration of the motor roots of the cauda equina after relief of pressure, and suture when required, theoretically is possible. Laminectomy for injuries which involve the cauda equina is not restricted by the limitations which experience has imposed in the treatment of injuries to the cervical and thoracic portions of the cord.

LAMINECTOMY

Anesthesia

In most spinal wounds thorough local infiltration with a 1 per cent solution of *procaine hydrochloride* containing 5 minims of *epinephrine* per fluidounce (30 cc.) is the anesthetic agent of choice In some instances light anesthesia produced with ether may be necessary *Morphine* is contraindicated in laminectomy for lesions situated high in the cervical region.

Technic of Operation

The patient must be carefully handled during the preparations for operation and when he is being transferred to the operating table, to avoid further injury to the cord. In laminectomy of the cervical or upper thoracic region, some form of cerebellar head rest is required.

In addition to an adequate instrumental armamentarium, a suction machine and a high frequency "damped wave" electrosurgical unit should be available, if possible.

For Injury by Projectile.—If the injury was caused by a projectile preliminary thorough débridement and irrigation should be carried out. Partial laminectomy already may have been accomplished by the projectile itself If not, the paraspinal muscles should be dissected from the spines and laminae of at least three vertebrae, centering at the point corresponding to the upper level of the zone of involvement of the cord.

The muscles are retracted and the spines are cut off with bone forceps. The laminae are then widely removed with angled rongeurs, so that the dura is disclosed. If the dura is not torn, it is opened longitudinally and the edges are retracted with retention sutures. The canal is cleaned by irrigation and suction or very gentle sponging with pledgets of moist cotton. Hematoma, fragments of bone, and foreign bodies are carefully removed. No attempt is made to repair the damaged cord. Bleeding is controlled by coagulation (if dural) by small transplants of muscle held over the bleeding points,

or by gentle pressure with cotton Troublesome extradural veins may require that strips of muscle be placed under the edge of the bone

A soft, small catheter should be run gently upward and downward within the dura If further obstruction exists, the bony opening is elongated

If the injury is very recent and the wound apparently is clean, an effort should be made to close the dura with fine silk. If the wound has not been seen soon after infliction, or in the presence of extensive damage to the dura, it may be left open, the cord being covered with a thin sheet of animal membrane, if this is available, but careful closure of the overlying muscle must be carried out. When the cord is exposed in the presence of obvious infection, the dura should be left partially open and a Penrose drain inserted to the depth of the dura A skin suture should pass through the edge of the drain to prevent its slipping in too far

For Fracture-Dislocation—The attachment of the muscles to the laminae must be separated carefully and the laminae removed This must be done without disturbance of the relationship of the fracture-dislocation to the injured portion of the cord. It is better to remove the bone above and below the site of dislocation, so that the point of greatest dislocation is approached gradually Removal of fluid below the zone of compression and the substitution of air for it will be helpful in determination of the lower level of subarachnoid compression at the time of operation As soon as the lower limits of compression are reached, the air will escape from the subarachnoid space The upper limits of compression are determined by the free escape of spinal fluid

The general principles to be followed for accomplishment of relief of pressure with the least possible disturbance of the spinal column should be followed No more bone should be removed than is actually necessary for relief of pressure Swelling of the cord arising from contusion usually will require that the dura be incised and left open

The wound should be closed in layers without drainage After cervical laminectomy the head, neck, and upper part of the thorax should be immobilized by the application of a plaster cast which extends to the lower thoracic region

If cervical dislocation has not been reduced prior to operation, skeletal traction achieved by skull tongs, as previously described, may be applied after laminectomy In the thoracic and lumbar regions, the advisability of hyperextension after laminectomy can be determined in consultation with an orthopedist.

GENERAL MEDICAL AND POSTOPERATIVE CARE

Whether or not operation is performed, general care of the patient is much the same and is of great importance. Complications are prone to develop, and not only may they seriously retard improvement in the condition of the lesion in the cord, but also they may of themselves constitute a menace to the patient's life

Drugs

In the postoperative period, *morphine sulfate* should be given freely if necessary and *sulfanilamide* or its derivatives should be administered regularly in doses of 1 gm. (15 grains) every four hours if possible. *Tetanus antitoxin* (1500 units) should be administered immediately after operation, with due precautions if tetanus antitoxin has been administered previously

The Wound

In the presence of infection, adequate drainage is essential. Drains and packs should be removed very gradually particularly if a fistula which drains cerebrospinal fluid is present. The surgeon should not hesitate to reopen part or all of the wound. Unexpected or unexplained elevation of temperature, chills, pain, tenderness, stiffness of the neck, or severe headache may be indications for this procedure.

The Skin

When the cord is injured, the skin, robbed of its sensation and its "trophic" innervation as well, is extremely sensitive to pressure. Large and deep decubitus ulcers will develop over every bony prominence unless the most meticulous precautions are taken. Frequent changes in position (*at least every two hours*, without twisting of the spinal column) and a smooth bed kept perfectly dry are essentials. Rubber rings and gauze "doughnuts" placed under pressure areas are unnecessary if the aforementioned measures are carried out carefully Best of all aids is an air mattress, together with plenty of pillows which are built up under the patient's thighs and knees, so that the heels hang free. Air cushions may protect against pressure over the sacrum.

The skin should be rubbed with a mixture of alcohol and camphor If pressure necrosis develops, careful local treatment, with removal of necrotic tissue and appropriate disinfection, is required. Every effort should be made to prevent infection. Treatment of ulceration by luminous heat and infra-red irradiation is of some help. The development of bed sores predisposes the patient to urologic infection and large bed sores are likely to be fatal.

or by gentle pressure with cotton. Troublesome extradural veins may require that strips of muscle be placed under the edge of the bone

A soft, small catheter should be run gently upward and downward within the dura If further obstruction exists, the bony opening is elongated

If the injury is very recent and the wound apparently is clean, an effort should be made to close the dura with fine silk If the wound has not been seen soon after infliction, or in the presence of extensive damage to the dura, it may be left open, the cord being covered with a thin sheet of animal membrane, if this is available, but careful closure of the overlying muscle must be carried out When the cord is exposed in the presence of obvious infection, the dura should be left partially open and a Penrose drain inserted to the depth of the dura A skin suture should pass through the edge of the drain to prevent its slipping in too far

For Fracture-Dislocation—The attachment of the muscles to the laminae must be separated carefully and the laminae removed This must be done without disturbance of the relationship of the fracture-dislocation to the injured portion of the cord It is better to remove the bone above and below the site of dislocation, so that the point of greatest dislocation is approached gradually Removal of fluid below the zone of compression and the substitution of air for it will be helpful in determination of the lower level of subarachnoid compression at the time of operation As soon as the lower limits of compression are reached, the air will escape from the subarachnoid space The upper limits of compression are determined by the free escape of spinal fluid

The general principles to be followed for accomplishment of relief of pressure with the least possible disturbance of the spinal column should be followed No more bone should be removed than is actually necessary for relief of pressure Swelling of the cord arising from contusion usually will require that the dura be incised and left open

The wound should be closed in layers without drainage After cervical laminectomy the head, neck, and upper part of the thorax should be immobilized by the application of a plaster cast which extends to the lower thoracic region

If cervical dislocation has not been reduced prior to operation, skeletal traction achieved by skull tongs, as previously described, may be applied after laminectomy In the thoracic and lumbar regions, the advisability of hyperextension after laminectomy can be determined in consultation with an orthopedist

and may result in rupture of the bladder If a catheter is passed *to determine whether or not obstruction is present*, however, infection may be introduced thereby and the purpose of the method may be defeated.

Tidal Drainage.—In cases in which incomplete paralysis is present, but in which there is some hope of recovery the "tidal drainage" method, although somewhat complicated, is advocated by many The apparatus consists of a reservoir containing saline or boric acid solution so connected with an inlying catheter by means of a "Y tube" that moderate intravesical pressure will result in overflow and siphonage of the contents of the bladder at regular intervals. If such an apparatus is unavailable, one end of the Y tube should be connected to a sterile bottle which contains an irrigating fluid. Irrigation should be carried out by this means every two days, and the catheter changed once a week. The patient should receive *sulfathiazole* 7½ grains (0.5 gm.) twice daily as a prophylactic measure.

Paralysis of the bladder among female patients can be satisfactorily treated by the insertion of an indwelling catheter and the daily instillation of antiseptic solutions.

The Bowel

The lower bowel, like the bladder may be paralyzed. Patients who have such paralysis should receive mineral oil regularly and usually will require, rather frequently strong cathartic agents or high cleansing enemas. Fecal impactions may necessitate manual removal.

Abdominal Distention.—This is a very common accompaniment of severe injury to the spinal cord. In some cases it is so marked as seriously to affect respiration among patients whose respiratory mechanism already is impaired. This complication may be very difficult to control. It varies greatly among patients who appear to have similar types of lesions. A measure of relief may be obtained in some cases by the insertion of a rectal tube. The hypodermic injection of *prostigmine* (1 cc. as an initial dose, with the subsequent administration of 0.5 cc. every four hours), is effective in many of such cases. Estimations of blood pressure should be made frequently while prostigmine is being administered.

Food and Fluids

There are no dietary restrictions (unless the abdominal or thoracic viscera also have been injured) Feeding should be begun im-

The Bladder

Care of the paralyzed bladder is always a problem in the management of injuries of the spinal cord, particularly among male patients The cooperation of a urologist is highly important. In the presence of severe injury paralysis of the bladder usually is complete There are retention of urine and, often, anesthesia. In milder injuries of the cord there may be retention associated with a sensitive bladder, so that evacuation of the bladder is required to prevent painful distention Several methods for the care of the paralyzed bladder have been used, none of which is entirely satisfactory. There is still much controversy as to the method which produces the best results

Suprapubic Cystostomy—This can be done as soon as it is determined that paralysis of the bladder is permanent or that the return of vesical function will be greatly delayed There should be no leakage around the drainage tube after performance of this procedure The method is especially applicable in cases in which infection already has arisen from catheterization, but it is also preferred in cases in which catheterization has not been done. Cystostomy should be carried out as soon as the patient's general condition permits it, and in many cases anesthesia is not required Prevention of cystitis with ascending infection, and the development of an automatic or "cord" bladder from which periodic overflow takes place when the pressure reaches a certain level, will perhaps be accomplished more often by this method than by any other. An automatic bladder is desirable if recovery of vesical function is not expected The development of an automatic bladder depends on the general condition of the patient. Automatic action of the bladder will not develop among patients seriously ill from sepsis caused either by bed sores or by urologic infection

Allowing the distended bladder to overflow without catheterization is strongly advocated by many as the method of choice Rapid renal damage due to back pressure and renal infection due to back flow may result, but the danger of infection from frequent catheterization is even greater If early transportation is necessary, an indwelling catheter should be left in place and irrigation of the bladder carried out as noted previously If prolonged observation is possible, the proper course to take depends on the likelihood of the ultimate return of vesical function Overflow may be facilitated by producing gentle massage of the suprapubic region The main objection to this method of producing overflow is the possibility that organic urethral obstruction is present, if it is, it will prevent the overflow

Chordotomy

If intractable pain makes the patient's life intolerable, he should not be abandoned to drug addiction. Section of anterolateral tracts will bring relief It should be performed only by an experienced neurosurgeon.

Treatment of Chronic Osteomyelitis

Persistence of drainage in a spinal wound should excite suspicion of osteomyelitis. Removal of sequestrated fragments of bone often will result in prompt healing.

mediately Fluids should be forced to a moderate degree to restore the depleted reserve and to combat urinary infection, but not sufficiently to prevent the maintenance of an effective concentration of *sulfanilamide* in the blood An intake of about 2500 cc of fluids per twenty-four hours is a satisfactory compromise Ingestion of a high-protein diet is essential for prevention of hypoproteinemia

Pulmonary Complications

Pulmonary complications constitute a constant threat in injuries to the spinal cord, particularly if the injury has occurred at the midthoracic level or higher, producing widespread paralysis of the muscles of respiration The frequent changing of the patient's position which is required for the prevention of bed sores also will do much to prevent pulmonary complications in these cases When lesions are situated high in the cervical region, with involvement of the phrenic nerves, the outcome nearly always is fatal The accumulation of bronchial secretion in the airways should be removed by suction Threatening failure of respiration which sometimes occurs in the presence of lesions situated high in the cervical region may require the use of a respirator

Contractures of Extremities

Contracture in both the upper and lower extremities may occur as a result of injury to the spinal cord Every effort should be made to prevent contracture by splinting, physiotherapy, and such other measures as may be determined by the orthopedists

LATE TREATMENT

Patients who have spinal injuries frequently will be invalids permanently Their lives may be prolonged and their suffering diminished by proper late treatment. The therapy of the bladder already has been mentioned Certain other measures also may be of importance All of them should for the most part be carried out in hospitals of the interior to which the patient is finally evacuated

Physical Therapy

In cases of incomplete damage to the cord, spasticity and pain may be partly alleviated and return of function enhanced by passive motion, massage, and hydrotherapy So-called muscle reeducation and the use of appropriate braces, crutches, or a wheel chair may return the patient to some measure of usefulness

a central protrusion of the disk. The pain is usually accentuated by coughing, sneezing, and straining at stool, and in about a fourth of the cases the pain is sufficiently severe at night to interfere with sleep. In a high percentage of cases, the patients complain of paresthesia in the involved leg or foot. Although rest in bed and the application of heat and massage to the muscles of the back may serve to give the patient relief of pain for a time, if a true protrusion of the disk has occurred, the symptoms tends to recur

Neurologic Examination

On examination the patient with a protruded lumbar disk often walks with a distinct limp with the trunk listed away from the side of the pain. Rarely he may list toward the side on which the pain is situated. There is a loss of lumbar lordosis. The erector spinae muscles are spastic. The motions of the spinal column are limited and hyperextension is usually exquisitely painful. Kernig's sign is often positive, and lifting of the straight leg usually is limited and painful, the pain being referred along the posterior aspect of the thigh and in the lumbosacral region.

In a few cases some sensation is lost over the lateral aspect of the involved calf or over the lateral and dorsal aspects of the involved foot, or over both calf and foot in the areas named. In many cases of protrusion of the lumbosacral disk patients have a diminution or absence of the Achilles tendon reflex on the side of the pain, although the reflex may be diminished or absent in cases of protrusion of a disk as high as the third lumbar interspace.

Spinal Puncture and Roentgenologic Examination

On diagnostic spinal puncture, the concentration of total protein in the spinal fluid is more than 40 mg. per 100 cc. in approximately two-thirds of the cases. A low value for the total protein does not exclude the lesion. The diagnosis may be confirmed in the majority of cases by the use of a contrast medium, such as air or radiopaque oil (Figs. 13 14) The accuracy of air does not approximate that of radiopaque oil but it has the distinct advantage that no radiopaque substance is left in the spinal subarachnoid space and air is much less irritating than the oil.* The finding of a defect at the level at which a lesion could and would produce the symptoms of which the patient complains is usually sufficient to confirm the diagnosis (Fig. 15) Ordinary roentgenograms of the spinal column without

* With increasing experience in using air or oxygen as a contrast medium it will be found to approximate the accuracy of oil.

to which their backs had been subjected was that which might result from extensive automobile riding. An illustration of this was a traveling salesman whose duties required him to drive his automobile 100,000 miles a year. If a man riding in a pleasure car has his back jolted sufficiently to cause a protrusion of an intervertebral disk, it is easy to see how a soldier operating a tank or a pilot dive bombing or landing on an airplane carrier might subject his back to sufficient stress and strain to produce a tear in the annulus fibrosus of the intervertebral disk with or without a tear in the posterior longitudinal ligament. This, in turn, would be sufficient to permit fragmentation and extrusion of a portion of the intervertebral disk into the spinal canal with a resultant nerve-root compression. It would seem logical also that parachute troops might occasionally injure their intervertebral disks in landing. If the force of landing should be directed against the buttocks with the back in flexion, injury of the intervertebral disk would be expected. Many patients are seen in civilian practice whose symptoms, caused by protruded intervertebral disk, began directly after a fall in the sitting posture. A good example of such injury is that which occurs when one slips on the icy pavement and sits down suddenly. Also, injury of the disk has been known to occur in cases in which individuals were pulling a heavy object toward them while walking backward. In these cases resistance suddenly was overcome and the sitting posture was assumed unexpectedly.

Onset and Distribution of Pain

The pain of which these patients complain is usually in the lower part of the back, and at a varying time after the onset of the low pack pain the pain is usually projected along the distribution of one or the other sciatic nerve. At the time of injury to the disk, the patient may feel or in rare cases even hear a snap in the back. At times, the patient even complains of loss of power in the lower extremities at the time of the onset of the protrusion, but more characteristically he has backache and after a period of a few days to a few weeks the pain extends down one sciatic nerve. The pain is usually unilateral because the central portion of the posterior longitudinal ligament is the strongest portion and the fragment of cartilage tends to be protruded to one or the other side of the spinal canal and impinges upon the nerve root crossing the disk at that point. Rarely, the patient may complain of bilateral sciatic pain, particularly if there is an unusually large fragment of cartilage or if the central portion of the ligament has given way and permitted

TREATMENT

The treatment of protruded intervertebral disk is removal of the protruded portion of the abnormal disk, which is pressing on the nerve root or spinal cord (Fig. 16) *Conservative treatment* consists *of strapping the lumbosacral region* with adhesive tape or of rest in bed on a hard mattress (boards under mattress) the application of

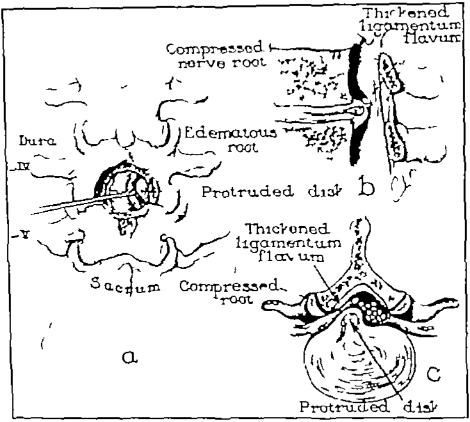

Fig. 17—a, Drawing illustrating the exposure of a protruded intervertebral disk after the performance of partial laminectomy; the spinous processes of the two adjoining vertebrae also have been resected; b and c, other views showing how the involved nerve root is compressed by the protrusion of the disk and the ligamentum flavum which is usually thickened and fibrotic in cases of long-standing protrusion of the disks.

heat and massage to the lower part of the back, and the use of bilateral Buck's extension on the legs. This should be tried for two or three weeks before considering surgical treatment unless there is unmistakable evidence of injury of nerve roots or the spinal cord, such as complete absence of the Achilles tendon reflex, loss of control of defecation or micturition, or the presence of anesthesia of the skin of the involved region.

Fig 13

Fig 14

Fig 15

Fig 13 —Anteroposterior roentgenogram of the lumbosacral region after the cerebrospinal fluid in the spinal subarachnoid space has been replaced with air One may note the shadow of the cul-de-sac deformed by the protruded lumbosacral disk

Fig 14 —Defect in the shadow of radiopaque oil caused by protruded lumbosacral disk.

Fig 15 —Defect in the column of radiopaque oil caused by a protruded lumbosacral disk which had resulted in intractable sciatic pain.

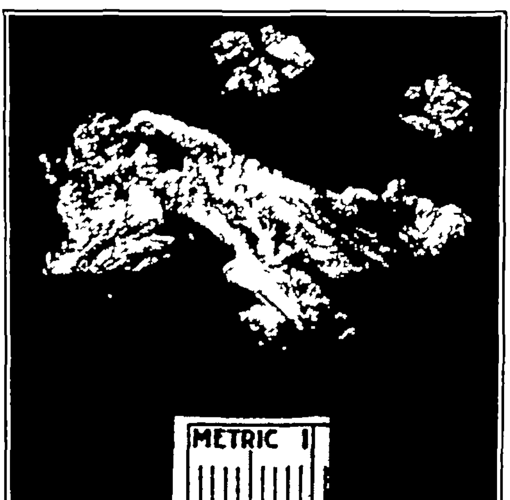

Fig 16 —Fragmented cartilage which protruded from an intervertebral disk and produced pressure on the nerve root.

a contrast medium are not diagnostic Narrowing of an intervertebral interspace may be suggestive but it is not pathognomonic

a snugly fitting canvas corset to support the back, particularly of parachute troops, dive-bombing pilots and those pilots whose duty necessitates their being catapulted from a ship and landing on an airplane carrier and tank drivers, might serve to protect the vul-

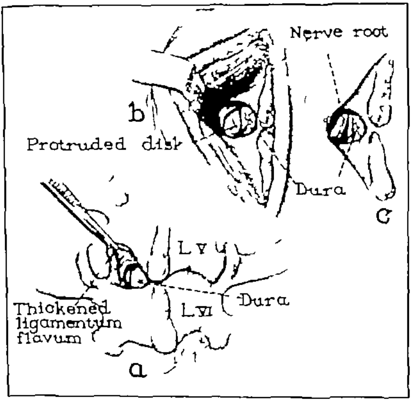

Fig. 19—Removal of a protruded intervertebral disk without the sacrifice of any bone; *a* the thickened fibrotic ligamentum flavum has been cut away from the laminae of the adjoining vertebrae by means of a small curved periosteal elevator in order to expose the underlying compressed nerve root; *b* the protruded portion of the intervertebral disk may be seen between the common dural sac, and the compressed nerve root has been displaced laterally and posteriorly; c, the protruded portion of the intervertebral disk has been removed and the nerve root has been relieved of pressure.

nerable lower part of the back and prevent injuries to the intervertebral disk and posterior longitudinal ligament and therefore decrease the number of protruded intervertebral disks which may otherwise occur

[Note The illustrations and much of the text of this chapter appeared in an article by Dr Love in "War Medicine," 2 403 (May) 1942.]

Laminectomy

Laminectomy (Figs 17, 18) is the surgical procedure which is most often employed After one has had considerable experience with this lesion, the protruded disk or disks may be removed in about 80 per cent of the cases without the sacrifice of any bone, that is, the ligamentum flavum at the interspace where the protrusion is situated is resected (Fig 19) Then the nerve root is retracted toward the midline and the protruded disk is removed without resecting the lamina Adequate exposure, however, is essential The patients are

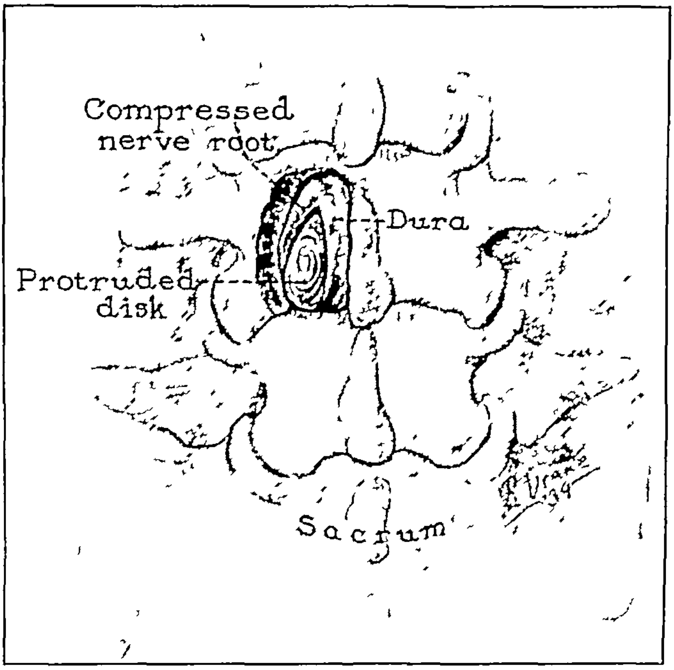

Fig 18—Hemilaminectomy for the exposure and removal of a protruded disk

usually kept in bed approximately two weeks if laminectomy has been performed, whereas, if no bone has been removed they are allowed up and around usually after five to seven days They should avoid heavy lifting and straining of the back for a period of three months after the operative removal of the protruded disk.

PROPHYLAXIS

Since most of the protruded intervertebral disks seem to occur while the patient's back is in flexion with unusual stress and strain on the back, it would seem that if some support were applied to the lower part of the back some of the protrusions could be prevented. A snugly fitting belt of the so-called sacro-iliac variety or

a snugly fitting canvas corset to support the back, particularly of parachute troops, dive-bombing pilots and those pilots whose duty necessitates their being catapulted from a ship and landing on an airplane carrier and tank drivers, might serve to protect the vul-

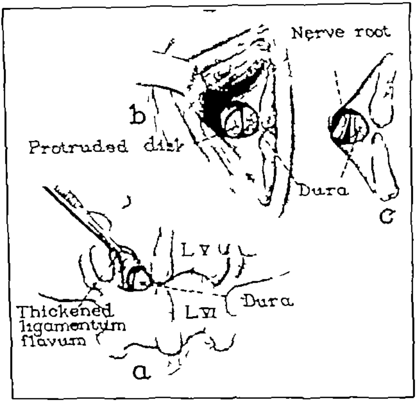

Fig. 19—Removal of a protruded intervertebral disk without the sacrifice of any bone: a, the thickened fibrotic ligamentum flavum has been cut away from the laminae of the adjoining vertebrae by means of a small, curved periosteal elevator in order to expose the underlying compressed nerve root; b the protruded portion of the intervertebral disk may be seen *between the common dural* sac, and the compressed nerve root has been displaced laterally and posteriorly; c, the protruded portion of the intervertebral disk has been removed, and the nerve root has been relieved of pressure.

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CHAPTER IV

INJURIES OF PERIPHERAL NERVES

BYRON STOOKEY M.D., and JOHN SCARFF M.D

INCIDENCE OF INJURIES OF NERVES

FROM statistics of casualties in the war of 1914–1918 it has been found that injuries to peripheral nerves constituted approximately 2 per cent of all injuries. The incidence of nerve injuries in wounds of the extremities, however is relatively high, being about 18 per cent of all extremity wounds (Table 1)

TABLE 1—INCIDENCE OF MOST COMMON INJURIES OF PERIPHERAL NERVES

Nerve	Frazier	Foerster	Pollock and Davis	Burrow and Carter
	2390 U.S. Army	3907 German Army	985 U.S. Army	1406 British Army
	Injuries			
Musculospiral	516	936	165	204
Median	269	800	93	242
Ulnar	492	742	136	527
Sciatic	551	523	160	121
Peroneal	395	183	120	97
Tibial	35	112	25	16
Circumflex		82	7	2
Musculocutaneous		71	4	24
Anterior crural		30	19	5

ANATOMY

The surgical treatment of nerves must at all times take into consideration the embryologic development of the nerves. Whether they be cranial, spinal, or sympathetic, all the nerves should be regarded

with the same consideration and handled with the same delicate manipulation that they would receive were they still within the central nervous system, of which they are an integral part. No surgeon would attempt to handle brain and spinal cord as if they were muscle and tendon Measures of repair applicable to mesodermic tissue obviously would not be applied to the central nervous system Nor would they be employed in the peripheral nervous system if it were appreciated that that system is made up of the same cells, derived in the same manner, and having approximately the same limitations, as the central nervous system itself.

Composition of Nerves

The typical nerve is made up of three groups of fibers, each with a separate origin—the *efferent or motor fibers,* derived from motor cells of the ventral column of the spinal cord or from the cephalic continuation of this column into the brain stem, of *afferent fibers* derived from ganglion cells of the spinal or cranial ganglia, and of *postganglionic fibers* from the sympathetic system (Fig 20). The efferent fibers leave the spinal cord along the paraventral sulcus to join the fibers from the distal part of the dorsal ganglia, thus forming the mixed nerve Those from the ventral part of the spinal cord to the point of union with the dorsal ganglion fibers form the *ventral root,* the *dorsal root* is formed by the fibers which leave the dorsal ganglia to enter the spinal cord at the paradorsal sulcus Separate motor and sensory roots are found in one or two of the cranial nerves, namely, the trigeminal and facial—the *portio minor* of the fifth cranial nerve constituting the motor root and the nervus intermedius the sensory root of the seventh cranial nerve The efferent and afferent components of the glossopharyngeal and vagus nerves enter and leave the brain stem together, but separate within it

Immediately after union of the dorsal and ventral roots, the spinal nerve redivides into *primary ventral* and *primary dorsal divisions* The latter passes backward, it does not enter into the formation of any of the plexuses for the supply of the musculature of the limb but, by union with the nerves immediately above and below, forms simple dorsal plexuses for the supply of the dorsal-axial musculature and overlying skin

The primary ventral division passes lateroventral to supply the lateral and ventral axial muscles and, in the region of the developing limb bud, forms the limb plexuses by redivision into secondary dorsal and ventral divisions In addition, the primary ventral division contributes preganglionic sympathetic fibers to the sym-

pathetic system. The preganglionic fibers terminate in sympathetic ganglia and are relayed by postganglionic sympathetic fibers to their ultimate distribution, some of them through the peripheral nerves. The sympathetic afferent fibers are derived from the dorsal spinal ganglia and pass via the sympathetic ganglia directly to the visceral structures from which they carry sensation. These fibers to the sympathetic system pass through the white ramus communicans. The

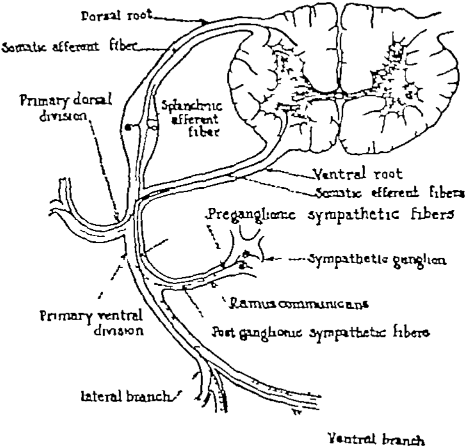


Fig. 20—Schematic drawing of a typical spinal nerve, showing its component fibers (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

postganglionic sympathetic fibers for the supply of the blood vessels, sweat glands, and so forth, of the trunk and limbs pass to the spinal nerves through the gray ramus communicans. These fibers are derived from the sympathetic neurons of the sympathetic ganglia. The peripheral nerves are thus made up of two types of neuraxes those from the central nervous system and those from the sympathetic nervous system. The majority of the former are medullated, while the latter are fine nonmedullated fibers. Each neuraxis consists of a slender

outgrowth which extends from its cell of origin to its distribution Thus, one fiber of the sciatic nerve extends from a ventral motor cell of the lumbar portion of the spinal cord or a lumbar spinal ganglion to the most distal parts of the lower extremity, in some instances 60 to 70 cm

Nerve Fibers

The neuraxis, or nerve fiber, is made up of *neurofibrils* embedded in a semifluid neuroplasm and surrounded by a delicate membrane —the *axolemma* In addition, some fibers have a medullary covering consisting of *myelin,* which is a chemical substance composed chiefly of lecithin, enclosed within a nucleated sheath called the *neurolemma* or "sheath of Schwann." These fibers are known as *medullated fibers* Others, devoid of myelin or medullary substance, but having an outer nucleated sheath similar to that of Schwann, are known as *nonmedullated fibers*

The function of the myelin is little understood. It is known, however, that it is not essential to conduction of the nerve impulse, since impulses are carried by nonmedullated as well as by medullated fibers, within both the central and the peripheral nervous systems

Both medullated and nonmedullated fibers are grouped into bundles in the nerves These bundles, called *funiculi,* are in turn grouped into a larger bundle surrounded by a covering of connective tissue called *epineurium,* this is derived from the surrounding mesodermal tissue, which has penetrated between the nerve fibers and nerve bundles during their early growth and surrounded the nerve The connective tissue between the nerve fibers is known as *endoneurium,* that between the nerve bundles as *perineurium*

Blood Vessels of Nerves

As the mesodermic ingrowth into the brain and spinal cord carries in the blood vessels, so does the mesodermic ingrowth into the nerves carry their blood vessels Blood vessels are richly scattered throughout the endoneurium, perineurium, and epineurium, and receive collaterals throughout their course In some instances a nerve has its own special artery as, for example, the sciatic nerve, but even this receives contributions from the neighboring vessels Appreciation of the rich vascular supply to the nerve is important, since extreme stretching of the nerve trunks to gain end-to-end apposition is likely to cause widespread rupture of the delicate blood vessels, with extensive intraneural hemorrhage, leading to secondary organization and interstitial sclerosis

Funicular Anatomy

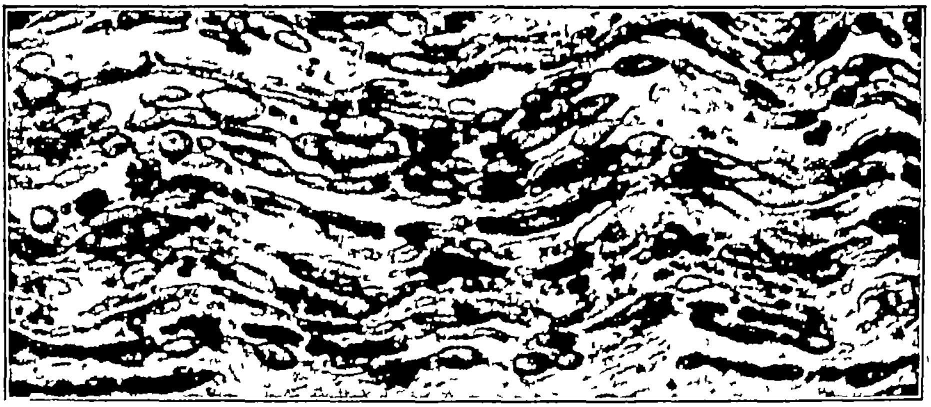
Within the nerves there is said to be a definite anatomic arrangement of the funiculi, certain funiculi being destined to certain muscles and having throughout the nerve trunk a constant and known position from their origin to their ultimate distribution. The view most widely accepted at present is that, except for one or two funiculi such as the bundle to the pronator teres, in the median nerve, a definite funicular arrangement is found only within a short distance of the point at which nerve branches are to be given off

Morphologically, the funicular arrangement varies with each cross-section, so that if 2 4 or 6 cm. of the nerve trunk are excised, the funiculi appearing in each section show a different arrangement above and below In consequence, clinical identification of corresponding funiculi would be impossible where there had been a loss of substance of 2 4 or 6 cm. or more. The proponents of funicular anatomy however have served to emphasize the tremendous importance of attempting accurate approximation without rotation of the nerve trunk. By reducing axial rotation to a minimum and bringing the medial aspect of the central end opposite the medial aspect of the distal end, more accurate approximation and less distortion of the funiculi result. Though some distortion is practically unavoidable, the more careful the avoidance of axial rotation, the more nearly will funicular approximation occur

DEGENERATION AND REGENERATION OF NERVES

Injury to a nerve trunk is followed by changes in the nerve fibers distal to the injury in the nerve fibers a few millimeters proximal to the injury and in the cell bodies of the injured fibers. In addition to changes in the neuron, evidences of injury are found in the neurolemma which ensheathes the nerve fibers in the myelin sheath and, in later stages, in the connective-tissue cells of the endoneurium and perineurium (Fig. 21) Changes are found, also, in the endings of both afferent and efferent fibers, in the periterminal network about the motor end-plates, and in skin, muscles, tendons, and bones which an injured nerve supplies. Injury to a nerve is thus followed by widespread secondary changes extending from the central nervous system to the most peripheral parts of the neuron and to tissues which the nerve supplies.

It was early appreciated that changes occur in the nerve distal to the injury that conduction ceases to take place, and that the nerve appears grayish and less glistening (Arnemann, 1787) It was



a

b

c

Fig 21—Degeneration of nerve fibers *a*, Distal stump of nerve cut three to five days previously (osmic stain), *b*, distal stump of a nerve partly cut twelve to fifteen days previously (osmic stain) Normal fibers and two nodes of Ranvier are shown at the bottom, *c*, distal stump of a nerve cut twelve to fifteen

not until 1852, however that Waller demonstrated that the nerve fibers were outgrowths of the nerve cell and were dependent on it for their nutrition. He described definite changes in the fibers following injury to which the name *wallerian degeneration* has been given.

Degenerative Changes in Distal Segment of Nerve Following Injury

Degenerative changes occur in the nerve fibers, the sheath cell, the myelin, and the connective-tissue covering of the nerve, a definite and more or less constant sequence of events taking place coordinately in the various tissues. At first no changes in the nerve fibers may be noted beyond the immediate point of injury but, within two or three days, beginning granulation and varicosities of the nerve fibrils are observed in most fibers throughout their length distal to the injury including the terminal arborizations. By the end of the third week nearly all remnants of the neurofibrils are lost except, perhaps, for a few scattered granules.

Coincident with the changes in the nerve fibers, changes are found in the myelin. These consist first of an irregular outline, followed by irregular segmentation and formation of discrete, irregular fragments of myelin. At the same time that degenerative changes are seen in the nerve fibers and myelin, again, important productive changes are taking place in the neurolemma cells. A marked increase in the protoplasm and in the nuclei occurs, with the appearance of granules in the protoplasm.

During the early stages of degeneration the sheath cells surround the myelin globules and the neurofibrillary remains and appear to remove these. The removal continues for eight or ten weeks after injury until gradually the neurolemma cells are free of all products of myelin and neurofibrillar degeneration.

Degenerative Changes in Proximal Segment of Nerve Following Injury

The degenerative changes in the central end, other than those seen at the immediate point of injury which may be considered traumatic, depend somewhat on the nature of the injury as well as on its proximity to the cell body. Tearing of the nerve and injuries near the cell body cause greater degenerative reaction than occurs if the nerve is sharply cut or if the injury is remote from the nerve cell.

days previously (osmic and Weigert's iron hematoxylin stain) In addition to the degenerating myelin, several band fibers and their nuclei (e.g. at n) are shown (Strong and Elwyn Bailey's Textbook of Histology Williams and Wilkins Co.)

If the injury is severe and close to the nerve cell destruction of the cell, without regeneration, may occur Thus, after severe injury to a nerve, and especially if the injury is near the cell body, destruction and complete degeneration of the neural elements in both the central and distal ends may take place, the degeneration extending from the cerebrospinal axis to the most peripheral terminal arborization

Regeneration of Neuraxes

Immediately following injury to the nerve fibers of the central end, fine new branches from the neuraxes may be seen, showing slight growth for a few days This may be looked on essentially as a local reaction to the injury and as more or less of an abortive attempt at regeneration Within three to five days in the case of medullated fibers, and in about ten to fourteen days in the case of some of the nonmedullated fibers, regenerative changes are seen at a slightly higher level than that of the immediate abortive regenerative efforts Within ten days the regenerating nerve fibers may be found within the connective tissue between the central and distal ends

So long as the nerve fibers are in the central end they assume a more or less parallel and orderly arrangement within the old sheath, except that now and then the fibers are spirally arranged about the neuraxes from which the branches are derived, forming a characteristic mass of regenerative fibers with occasional end buds When the scar tissue at the point of union is met, the fibers lose their orderly arrangement and are seen as irregular masses Some may escape into surrounding tissue and become lost, others pass through to reach the distal end, within which they again assume a smooth, parallel, and orderly course In most instances nerve fibers can be found in the proximal end of the distal stump within ten days, but this depends on the accuracy of the line of suture and the degree of scarring—a longer time being required when suture is imperfect and the scar thick.

Study of serial sections at the line of suture emphasizes the importance of leaving the least possible opportunity for formation of scar between the nerve ends There is no evidence to indicate that selectivity and rearrangement of the nerve fibers take place at the line of suture The evidence would seem to point to the fact that a larger number of neuraxes are sent out from the central end than was originally to be found Downgrowth is attempted by all—these neuraxes, efferent and afferent nerves traversing each other's channels probably as far as the muscles and the skin Those efferent fibers

which reach muscles form motor end plates, while those which reach sensory areas, finding no functional arborization to be made are pushed aside and replaced by fibers which can establish functional connections (Table 2)

TABLE 2.—FACTORS GOVERNING PROGNOSIS AND TIME OF REGENERATION OF VARIOUS NERVES

Variants controlling regeneration (1) nerve injured (2) level of injury (3) mechanics of suture (4) condition of nerve ends (5) condition of wound and nerve bed (6) interval between injury and suture.

Approximate Time for Expectant Evidence of Regeneration

Nerve and Level	Under Good Conditions (Months)	Under Poor Conditions (Months)
Musculocutaneous		
Axilla	5–6	8–10
Musculospiral		
Middle third arm	7–8	14
Lower third arm	6–7	12
Ulnar:		
Wrist	5–7	10
Elbow	10–12	16
Axilla	15–16	22
Median:		
Wrist	4–5	10
Elbow	8–9	15
Axilla	12–14	22
Sciatic		
Middle third thigh	10–12	18
Upper third thigh	12–14	22
Peroneal.		
Head of fibula	8–9	14
Popliteal space	10–12	16
Tibial		
Popliteal space	11–12	17

In regeneration of the nerves, all fibers, whether originally medullated or nonmedullated, appear at first devoid of myelin. Only later does myelin appear beginning centrally and proceeding toward the more distal portion. Thus, myelin is seen first in the older parts of the regenerated fibers. It is interesting to note, in this connection, that regeneration of the motor end plates and of the muscle, and the return of some volitional control, take place before myelinization is to be found.

Downgrowth of nerve fibers with nerve transplants, whether the transplants be autogenous, homogenous, or heterogenous, occurs in essentially the same manner as when end-to-end suture is done, except that two lines of scar tissue must be passed Connective-tissue union of the transplant and nerve ends occurs at both points of suture No special unfavorable connective-tissue or fibroblastic response is found in heterogenous nerve transplants, although the reaction is greater in these than in autogenous and homogenous transplants When autogenous cable transplants are used, connective tissue is found growing about them and between them, converting the cable transplant into a single nerve trunk The neuraxes penetrate the sheaths of the transplant and grow mainly through them to the distal end Some may be met within the connective tissue between the fibers of the transplant The arrangement is orderly and parallel, being essentially the same as when nerve fibers have reached the distal end after end-to-end suture The rate of growth is approximately that found in end-to-end suture, depending on the precision of the suture and the nicety with which end-to-end approximation of the graft is made

CLINICAL MANIFESTATIONS OF INJURY TO NERVES: GENERAL CONSIDERATIONS, METHODS OF EXAMINATION

History and Nature of Injury

The location and nature of the injury, whether it be a sharply incised wound, a contused wound, or an injury due to considerable violence, are important and influence materially the decision as to whether operation should be attempted or withheld One person, riding on a motorcycle, strikes a telegraph pole with his shoulder and total paralysis of the brachial plexus results Another receives a blow from a club over the arm, with paralysis of the musculospiral nerve Obviously, injuries produced by forces of such different character themselves differ both in extent and in pathologic characteristics.

Time of Paralysis—It is important to inquire of the patient whether he noted immediate paralysis of the muscles supplied by the injured nerve or whether paralysis came on gradually Frequently the patient is unable to answer this question but, if an accurate answer can be obtained, it is of value If the weakness and paralysis appeared gradually, the lesion probably is due to scar tissue involving the nerve secondarily or to compression of the nerve by callus, whereas if the paralysis was noted immediately, anatomic

interruption or severe anatomic damage to the nerve is the more likely explanation.

Examination of Site of Injury

The region of the injury should be palpated for scar and callus, for the presence of neuroma, and for induration of the nerve above and below the level of the injury. Palpation of the nerve trunk may determine (1) the exact level of the injury, (2) whether anatomic continuity is sustained or lost, and (3) the presence or absence of intraneural fibrosis in the proximal and distal segments. This simple examination is valuable and too often is neglected. The adjacent structures also should be palpated, especially in the vicinity of the great vessels if aneurysm is suspected. In the case of gunshot or shell wounds of extremities, the site of injury to a nerve often can be told fairly accurately by the situation of the scars of entrance and exit.

Motor Examination

The action of each muscle supplied by the nerve should be studied. Gross movements, such as flexion of the wrist or fingers, are of little value, since they can be accomplished even with total paralysis of one or more nerves. Movements normally performed by a synergic muscle unit may be taken over by a single member of that group, or muscles under the domain of one nerve may assume functions usually served by another muscle and other nerves. These supplementary movements, or "trick movements" as they are sometimes called, may mask the actual paralysis of certain muscle groups and lead the novice to false deductions. With total interruption of the musculocutaneous nerve and paralysis of the biceps muscle, for example flexion of the forearm may be accomplished by the supinator longus supplied by the musculospiral nerve.

Significant Movements.—Some of the movements which cannot well be simulated are as follows (1) extension of the wrist and of the proximal phalanges of the fingers and thumb in the presence of lesions of the musculospiral nerve; (2) abduction of the fifth finger in a plane with the palm, without flexion of the finger in the presence of injuries of the ulnar nerve also under the same circumstances, extension of the distal phalanges of the fingers when the proximal phalanges are extended, (3) flexion of the distal phalanx of the thumb and index finger in the presence of injuries of the median nerve and (4) dorsiflexion of the foot and ankle in the presence of injuries of the peroneal portion of the sciatic nerve.

Palpation in Testing Movements.—When studying function of a

muscle, both the belly and the tendon of the muscle should be palpated during attempts at contraction, to determine more accurately than if only one is palpated, the action of the muscle in question Examination of the motor mechanism also can be made by testing movements which bring out normal associated acts These do not depend on volition but are associated reflex connections which cannot be controlled or simulated

Loss of Deep Reflexes—Loss of the deep reflexes is seen with lesions of some of the nerves In injury of the musculocutaneous nerve, the biceps jerk is lost, in musculospiral injuries the triceps jerk, and in sciatic nerve injuries, the Achilles jerk. Since the reflex is abolished irrespective of the severity of the lesion, its loss does not aid in distinguishing between complete severance or physiologic interruption of a nerve.

Atrophy and Tone

When muscle is deprived of its nerve supply, it undergoes atrophy Atrophy is determined by the size of the muscle as compared with the corresponding muscle of the opposite side It is more marked in small muscles, such as those supplied by the ulnar nerve. Extent of the atrophy is appreciably influenced by the care given the extremity after the injury and the amount of movement the muscle has had, either passive, due to the action of the other muscles, or as the result of massage The degree of atony parallels closely that of atrophy. When there is marked atrophy, marked atony is also present.

Electric Examination

Examination by both faradic and galvanic currents is indispensable, though a wide clinical experience reduces its significance The *faradic response* of both nerves and muscles is absent in any condition in which conductivity is lost, whether the interruption be anatomic or physiologic The faradic response is lost early and usually is the last response to return, often being wanting even when voluntary contraction of the muscle has reappeared The *galvanic current* is of greater value in determining finer changes, though neither the faradic nor galvanic current makes possible differentiation between anatomic and physiologic interruption Hence, from an anatomic standpoint, in severe compression and in anatomic interruption the degeneration of the nerve fibers and muscle fibers is identical In both the muscle may be completely deprived of its nerve supply

By use of the *Jones condenser current,* a quantitative determination of the degeneration can be obtained. Normal intact muscle re-

sponds to 0.03 to 0.05 microfarads. When a stronger current is required, degeneration is present, its degree being proportional to the extent of current required to obtain a response. When no response is obtained up to 2.0 microfarads, complete reaction of degeneration is present, and the muscle has undergone marked degeneration. Such muscle is practically devoid of contractile tissue.

Chronaxie

It has long been known not only that the intensity of the current plays a part in the study of excitability but also that the time required for the passage of the current is an important factor. Lapicque introduced the idea of chronaxie in physiology. The chronaxie is the time of passage of the current necessary to produce the threshold of contraction with an intensity double the rheobase. The rheobase is the threshold of galvanic current. By means of a system of appropriate resistance Bourguignon was able to eliminate the resistance of the skin and thus introduce into clinical work measurement of the chronaxie. By discharge of condensers one can obtain currents of definite duration.

Chronaxie of the normal skeletal muscles in man varies from 0.06 milliseconds to 0.7 milliseconds, according to the muscle groups examined. Muscular groups having the same function in the same segment of an extremity have the same chronaxie. This law has been found to exist through the whole animal series. In the study of pathologic conditions of muscles, chronaxie has proved to be of value. In neuromuscular degeneration the chronaxie may be increased two hundredfold. Thus, the chronaxie may be raised from 0.06 millisecond to 30 or 40 milliseconds. In reflex atrophy or in lesions of the pyramidal tracts, for example, the chronaxie is seldom elevated to more than four times normal. Thus, this method permits one to determine whether the paralysis or the atrophy is due to a lesion of the lower motor neuron or to one of the upper motor neurons. In primary muscular disease, such as myopathy, the values for chronaxie are close to normal.

Alterations in the chronaxie occur early in the disease. Thus, the physiopathologic changes in neuromuscular status can be determined early. In addition, estimation of the chronaxie enables one to evaluate the precise degree of neuromuscular degeneration. Repeated examinations permit the evolution of the lesion to be followed and thus, whether the lesion is progressive or whether regeneration is taking place can be determined. Hence, chronaxie has a prognostic as well as a diagnostic value.

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sensory nerves. According to Stopford, the assumption of a separate set of fibers for deep sensibility has no anatomic basis in fact; but the so-called cutaneous or sensory nerves supply the deep structures, such as the joints, with sense of position and movement, the impulses being transmitted through the digital branches. In the presence of injury of a median or ulnar nerve, whether at the wrist or forearm, or in the arm, the sense of position and spatial recognition is lost in some of the phalangeal joints. Thus, deep sensibility is lost in association with injuries distal to the level at which muscular branches or deep branches are given off Hence, this form of deep sensibility can be transmitted through fibers which do not pass with the motor branches. Stopford found that accurate localization of pressure sense is possible through deep sensation alone and that recognition of movements may be lost with some ability to localize, while at the same time pressure as such, can be readily recognized. It may even be that less pressure is required to produce pressure pain than is normally necessary

In regeneration, recognition of contact and appreciation of pressure pain recur early usually during so-called protopathic recovery while recognition of localization and spatial position of the joint occurs late, not until return of epicritic sensibility Thus, deep sensibility like the more superficial forms of sensation, may be subdivided into (1) discriminative that is, recognition of the joint moved and the direction and extent of the movement; (2) affective that is, recognition of contact, pressure and sense of movement.

Mechanisms Involved in Discriminative and Affective Sensations. —Stopford expressed the view that the division of sensation into discriminative and affective forms is not dependent on differentiation of two sets of fibers within the peripheral nerve but that the difference lies in the central nervous system. The discriminative types, which return late or not at all, are essentially cortical in their representation. They are cortical connections with wide ramifications hence, after suture and regeneration, rearrangement of the fibers, their terminals and collaterals, as well as of the impulses which they receive, constitutes a difficult problem of cortical readjustment. The more primitive, affective types of sensation, such as pain, response to extreme degrees of temperature, contact, pressure, and sense of movement as such, without recognition of spatial relations, are less highly developed, and require less intricate rearrangement of the neurons. Thus, the phylogenetically older types represent simpler sense mechanisms, whereas the newer modalities of sensation, concerned with discrimination, are more complex, being dependent on

Longitudinal Reaction

The point at which the muscle gives a maximal response to the minimal stimulus is called the *motor point* This corresponds to the point where the nerve enters the muscle Stimulation here stimulates the branch of the nerve that goes to the muscle and, consequently, the entire muscle After degeneration of the nerve, stimulation of the motor point no longer gives the maximal response This is now found at the junction of the muscle fibers with the tendon, since at this point the muscle fibers come together and a greater number of them are stimulated at this point than would be the case if the electrode were applied elsewhere to the muscles The motor point no longer gives a rapid response, since degeneration of the nerve has taken place and nerve fibers no longer are present there, only the muscle fibers are stimulated and the response is consequently diminished This has sometimes been called "descent" of the motor point, a somewhat misleading term

Myotatic Irritability

Muscle fibers freed of neural connections and inhibitions respond with increased activity to direct mechanical stimuli, such as tapping the muscle This phenomenon is known as "myotatic irritability"

Sensory Examination

Forms of Sensation—The most fundamental study of sensation has been made by Head, Rivers, and Sherran, who showed that areas usually designated as areas of diminished sensation really represented total loss of some form of sensation, with retention of others The lost sensations were of the epicritic or discriminative types, that is, those forms evoked by cotton wool, moderate degrees of temperature, and so on The retained sensations were the protopathic or affective forms, called forth by pain and extreme degrees of temperature, and a third form, which Head listed as deep sensibility

Deep Sensibility—The brilliant work of Head and his collaborators served to clear up the confusion which had theretofore existed in all descriptions of sensation and paved the way for many forms of sensory study His division of sensation into epicritic, protopathic, and deep sensibility was almost universally accepted until the painstaking work of Stopford (1922) showed that deep sensibility could not be considered as a separate form of sensation, served by a separate set of fibers which reached their receptors through motor nerves and which consequently were not destroyed by division of cutaneous

Temperature sense is best tested by large, conical, thin, metal tubes, having relatively small, tapering ends. Metal affords better radiation than glass and the large tubes keep the temperature more or less uniform during the examination *because of the quantity of* fluid which they contain.

Charts should be kept showing the areas of altered sensibility so that comparisons can be made at subsequent *examinations*. Only by comparison of several examinations can any definite prognosis be made as to recovery of sensation.

Impossibility of Distinguishing Clinically between Anatomic and Physiologic Interruption

In the presence of complete loss of function, one group of signs has been attributed to lesions associated with anatomic interruption of the nerve trunk, and another to lesions producing complete interruption of conductivity without anatomic interruption. These two groups of signs have been said *to differ sufficiently to* permit distinction to be made between physiologic and anatomic interruption. The importance of the differentiation cannot be overestimated. If it be known that anatomic continuity is lost, surgical intervention is at once indicated. On the other hand, many hold that when continuity is not lost, surgical measures are not indicated, at least until a later date.

Unfortunately however the syndrome ascribed to anatomic interruption applies about as often to complete loss of function due to compression with anatomic continuity The distinction between these two groups, therefore has been abandoned by most observers, who recognize that the distinction is artificial and the distinguishing points inaccurate. In cases in which patients have been treated expectantly for months on the assumption that the *loss of function* was due only to interruption of conductivity operation has revealed complete anatomic interruption, with the nerve ends separated in such manner that spontaneous regeneration was impossible.

Only presence of a severe lesion of a nerve can be inferred when all function of the nerve below the level of the lesion has been lost. Compression, with anatomic continuity may be as severe a lesion as interruption. Interruption of all conductivity and total loss of all function may exist when the compression is severe or when it is slight. Functionally and so far as the neurologic signs are concerned, these two cannot be distinguished with sufficient reliability to warrant advising against exploration. It has been an almost invariable rule that the nerve ends and the surrounding tissues have been

intricate associations within the cortex Failure of recovery of the discriminative forms of sensation after nerve suture is probably due not to failure in downgrowth of neuraxes through the line of suture and into the distal segment, but to failure of the cortex to reestablish new associations

Nerve Overlap—Pollock's thorough study of the areas of protopathic sensation has shown that the area of loss to pain and of loss of response to extreme degrees of temperature is greater in the early stages following section than in the later stages, but that before regeneration occurs this area of lost sensation diminishes He has also shown that this apparent return of sensation represents the area of adjacent nerve overlap Functions served by both nerves in the region of overlap are gradually assumed by the uninjured nerve the fibers of which are distributed to this region Appreciation of the existence of such nerve overlap is as important in sensation as appreciation of supplementary or trick movements in motility Failure to recognize its presence has been responsible for reports of early recovery of sensibility which could not possibly have been due to regeneration of nerve fibers Pollock's studies have been thorough, and there can be no doubt as to the correctness of his conclusions Cushing (1904) showed that encroachment of the surrounding nerves into the trigeminal nerve area took place some time after extirpation of the gasserian ganglion Studies in phylogenesis have shown that one nerve may take over the cutaneous area of an adjacent nerve

Constant and Measurable Stimuli in Examination—If comparisons of sensory findings are to be made, the sensory examination must be done with constant and measurable stimuli Experience is needed in testing the various forms of sensation The borders of sensory changes should be determined by tests parallel to the limit of the nerve area in question, so as to avoid infringing on areas within the domain of adjacent nerves In testing sensations of pain, some form of algesiometer should be used

Temperature in Examination—Not only should constant and measurable stimuli be used, but also consideration given to the temperature of the extremity at the time the examination is made Head and Rivers, Burrows and Carter, noted relapse of sensibility from the delicate epicritic to the more primitive protopathic under the influence of low temperature in cases of injury to nerves during recovery Since the temperature of a paralyzed extremity is usually lower than that of the normal extremity, the paralyzed limb should be warm if accurate sensory determinations are to be made

of the nerves. In the majority of cases the tendency is to spontaneous recovery in periods of from several months to one or two years. The injury to nerves is incomplete, usually some motility and some sensation are retained. Frequently the suggestion of muscular contraction can be seen. The electric reactions show incomplete response but not the reaction of degeneration. Hyperesthesia of the skin and often of the deeper structures is found. The slightest touch is painful, causing a vague diffuse sensation, with considerable dispersion and radiation. Touch, pin prick, and temperature evoke almost similar responses, the patient often being unable to distinguish between the disagreeable sensations evoked by all. The muscle bellies and the nerve trunks are extremely tender to pressure and radiation of the pain is widespread.

Pain is spontaneous, characterized by burning, pricking, and sensations of extreme cold and extreme heat. It is interesting to note that irritative lesions of the fibers carrying sensations of pain in the peripheral nerves give rise to subjective sensory disturbances comparable to those encountered when the lateral spinothalamic tracts of the spinal cord are irritated by tumor or disease of the spinal cord or by lesions of the thalamus itself—so-called central pain.

Causalgia, an extremely severe form of nervous irritation, constituting a definite clinical entity will be discussed in a section to follow dealing with a group of special conditions (p. 168)

Trophic Disturbances

Trophic changes are the most characteristic objective findings in the various forms of irritation of nerves. They extend throughout all the tissues, the skin, nails, muscle, fascia, articular and periarticular tissues, and even the bones (Fig. 22, *a* and *b*) It is these changes which make irritation of nerves a more severe lesion than interruption of nerves since, even if spontaneous recovery takes place, marked secondary changes persist in joints, muscles, and periarticular tissues, more disabling than total paralysis of the nerve involved. Fibrous changes in the muscles make them hard and boardlike and all but devoid of contractility The periarticular changes about the small joints of the hand fix these joints so that little or no motility is possible. The skin remains red and glossy and often sweats freely the sweat dripping from the tips of the fingers under emotional stress (Fig. 23) Because of the severe pain, these secondary changes cannot be treated by physical therapy and contractures cannot be prevented by mechanical means until after the pain has subsided. At that time the secondary changes are well advanced and resist all

found at operation to be more severely injured than the neurologic signs would have led one to believe

Signs of Compression and Interruption—The points which are said to distinguish compression from interruption are as follows In compression there is preservation of tone, atrophy is rapid in onset but is less severe than in interruption, and the reaction of degeneration is incomplete and slow in its appearance On the other hand, the conditions have the following signs in common complete paralysis, complete sensory loss, absence of spontaneous or induced pain along the nerve or belly of the muscle, absence of formication, and absence of marked trophic disturbances unless these are secondary to trauma

TONE—The degree of tone retained is extremely variable, depending on the muscles involved, the interval between injury and examination, the extent of fibrosis and articular and periarticular changes Tone, therefore, cannot be taken as a valuable and reliable distinguishing point.

ATROPHY—The degree and extent of atrophy are also inconstant Small muscles undergo more rapid and apparently more extensive atrophy than larger muscles The degree of atrophy is also influenced by the passive movements which are imparted to the muscles by movements of neighboring muscles and by measures of physical therapy Unless these are known and controlled, atrophy can hardly be considered a reliable sign by which to distinguish interruption from compression of a nerve

ELECTRIC REACTIONS—The electric reactions likewise are inconclusive It may be true that a complete reaction of degeneration is less often found in the presence of compression than in association with interruption, except when the lesion is of long standing As a means of distinguishing between interruption and compression, however, this may not be significant since, even in the presence of complete interruption, a complete reaction of degeneration may not appear until late Thus, in the early stages the responses are likely to be the same

Sharply defined syndromes represent attempts to create an artificial distinction between anatomic and purely physiologic interruption of the nerve when, in fact, little or no functional or even anatomic distinction exists

Nerve Irritation

All gradations of irritation of nerves, from the slightest to the most severe, may be met with in association with traumatic lesions

measures to reestablish motion, even though faithfully tried for a number of years after recovery of nerve function. Unfortunately, in many of these cases treatment is not surgical, since the pain disappears spontaneously and the nerve lesion is recognized as incomplete. When, however, it is appreciated that the secondary changes may produce far greater disability than even total loss of nerve function, some form of active surgical treatment should be undertaken, such as alcoholization of the nerve trunk or actual cutting of the nerve with immediate suture.

Signs of Regeneration

In Absence of Neuraxial Degeneration.—Regeneration of the neuraxes is followed by more or less definite signs, having a definite sequence, whether the degeneration has been due to anatomic interruption or compression. When, however loss of function has been due to physiologic interruption of conductivity without sufficient pressure to produce degeneration of neuraxes, return of function is resumed along the anatomically intact neuraxes. The anatomic path is intact, the physiologic path alone has been inhibited. Consequently function may reappear within a few hours or days after liberation and in no regular sequence. In some instances liberation is followed within an incredibly short time by return of voluntary motion of the part previously paralyzed. Sensation may return as rapidly as motion, the discriminative and affective forms frequently appearing at the same time.

After Neuraxial Degeneration.—When regeneration takes place after degeneration of neuraxes, its evolution is more constant. Subjectively the extremity "feels different," is "freer" Thus occurs not infrequently soon after operation—too soon to be of much value as a sign. The first objective sign is a change in the vasomotor status of the part. The circulation is improved, and the color and texture of the skin approach normal. Bellies of muscles previously insensitive to pressure become painful when pinched—this before any evidence of contraction of the muscles is to be found and frequently before any change in cutaneous sensibility has been noted. A gradual increase in the tone of the muscles becomes evident. If the galvanic current showed polar inversion, it now begins to show polar equality The slow, undulating response to galvanism becomes more rapid. The longitudinal reaction disappears and the maximal response is again found at the motor point instead of at the point at which the muscle fibers enter the tendon.

The faradic response is extremely slow to return, frequently

a

b

Fig 22 —*a,* Trophic changes in fingernails of second and third fingers due to trauma in association with paralysis in the region of distribution of the median nerve, *b,* ulcer on sole of foot due to trauma in association with paralysis in the region of distribution of the sciatic nerve (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

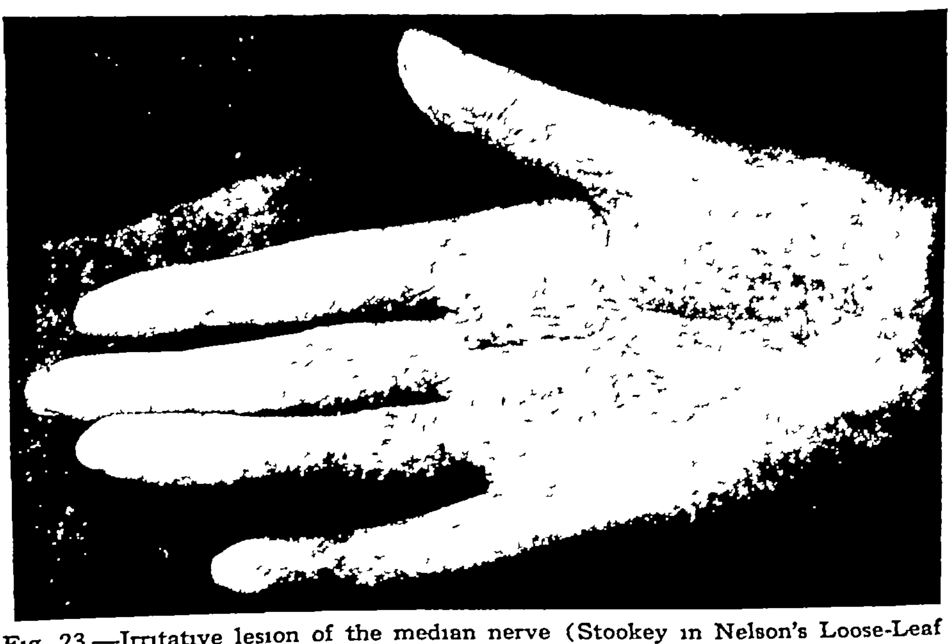

Fig. 23 —Irritative lesion of the median nerve (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

is injured only a short distance above the point at which a group of branches is given off, innervation of the muscles supplied by these branches may take place relatively early, whereas if a considerable distance intervenes between the point of injury and the origin of branches, a longer period must elapse. Additional factors influencing the rate of regeneration are the interval between injury and suture, a history of infection or the lack of it, the presence or absence of intraneural fibrosis, the character of the nerve ends, the degree of tension, the type of operation, the nature of the nerve bed, and the preoperative and postoperative treatment.

Signs of Interrupted Regeneration

Reexploration following failure of a nerve to regenerate can be undertaken earlier when signs of regeneration have not appeared than when they have been present but have not progressed. Interrupted regeneration should be suspected when signs of returning function have become stationary It may occur at any stage, but seldom happens if definite evidences of degeneration have appeared. Temporary retardation of regeneration is sometimes encountered. The signs must, therefore, be adjudged with full knowledge of the conditions of the anatomic fields, the degree of tension, and the appearance of the nerve ends. Immediately after operation a presumptive prognosis, based on the conditions of the operative field, the degree of intraneural fibrosis, and the mechanics of the suture, should be indicated in the operative report for future reference. When spontaneous regeneration without operation becomes arrested, exploration should be made earlier and with less hesitation than when the conditions of the anatomic field and the position of the nerve ends are known.

End Results of Repair as Factor in Determining Surgical Policy

Anatomic Standards of Regeneration.—In the admirable report of Forrester Brown, the criteria of regeneration were complete, incomplete, or absence of, sensory return and complete, incomplete, or absence of return of motor function. When judged by such rigid standards, complete regeneration is, of course, rarely obtained because of the histologic structure and function of the nerve bundles and their spinal and cerebral connections. Further injury of a nerve at levels at which the branches are given off precludes the possibility of regeneration of the muscles supplied by the branches, since the branches to the muscles have been destroyed at the time of injury Suture of the nerve would not restore function of these muscles unless arti-

not appearing until after voluntary motion is present, so that it is of little value in ascertaining the presence of regeneration.

Pain on pinching the skin in areas in which pain heretofore has been lost is a valuable early sign of regeneration. As regeneration progresses, the *protopathic* forms of sensation, both superficial and deep, appear, that is, recognition of pin prick, contact, and pressure pain With improvement of these, response to the lighter forms of contact begin to return, and less pressure is needed to elicit pressure pain. Rather late in the progress of regeneration, tactile and joint localization appear, though even in the late stages these are defective The *discriminative* forms of sensation frequently remain defective for a long time, in some cases permanently, even after recognition of touch as such has returned Touch localization, with discrimination as to the character and quality of the sensation, and spatial recognition of joint movements are the last forms of sensation to return. Recognition of defective sensation of this character is of extreme importance to pension and industrial compensation boards, since response to touch is not necessarily accompanied by recognition of the quality or localization of the contact

Tinel's Sign

A creeping sensation referred to the peripheral distribution, elicited by pressure over a nerve trunk, indicates, according to Tinel, the presence of "young axis cylinders in the process of regeneration" Unfortunately, Tinel's sign has been found to be of little value But although its occurrence along the nerve trunk alone cannot be considered evidence of satisfactory regeneration, it is of value after suture of a nerve or liberation of a nerve when the anatomic field is known. Here its main limitations are removed, since the nerve ends are known to be in apposition and in position to favor downgrowth. When regenerating fibers are present, the level on the nerve trunk at which the sign can be elicited gradually descends step by step with the downgrowth of the neuraxes Hence the lowest level at which the sign is found should be determined at each examination

Time Required for Regeneration Following Suture

Evidences of regeneration are rarely found earlier than the third or fourth month and may appear any time thereafter, even up to thirty months The time required is influenced by many factors which make it impossible to set a definite standard applicable to all nerves The period varies with each nerve, the level of the injury, and its relation to the origin of nerve branches When a nerve trunk

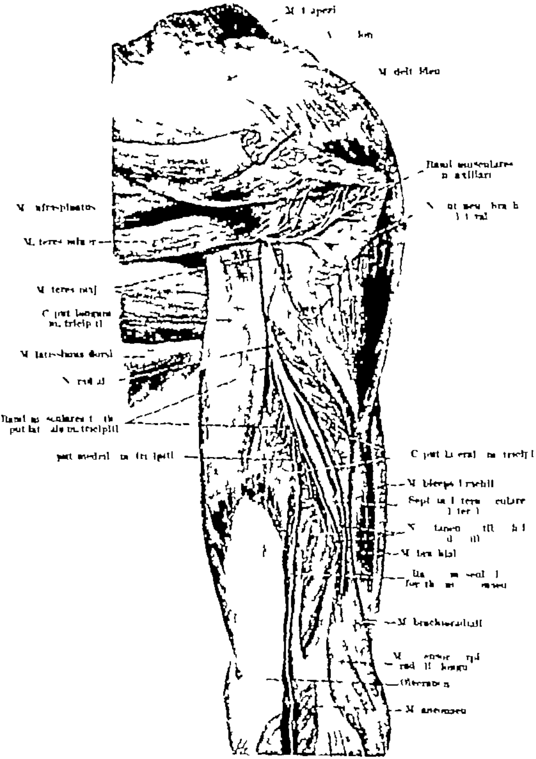

Fig. 24.—Nerves of the upper part of the right arm, viewed from behind (Spalteholz: Hand Atlas of Human Anatomy Vol. 3. J B. Lippincott Co.)

be well founded, namely, that "there was no constancy in the rate of recovery of any particular nerve, that the rate was not definitely influenced by the level of the lesion, or absolutely by the period since operation" Furthermore, "the degree and rate of recovery were not influenced by the length of time between injury and operation, the duration of the initial sepsis, or the recrudescence of sepsis after the nerve operation"

CLINICAL MANIFESTATIONS OF INJURY TO NERVES· CONSIDERATION OF INDIVIDUAL NERVES

Musculospiral or Radial Nerve

Course and Distribution—In war wounds, the musculospiral nerve is the most frequently injured of all the nerves of the body It arises from the posterior cord of the brachial plexus and bends around the back of the humerus where it lies under cover of the triceps muscle It appears on the lateral surface of the humerus and then on the anterolateral surface of the musculospiral groove From here it descends between the supinator longus (or brachioradialis) and the biceps muscle to the elbow Just below the elbow it divides into its terminal branches, the radial (or superficial branch of radial) and the posterior interosseous (or deep branch of radial) The radial (or superficial branch of radial) nerve is a purely sensory nerve It descends under cover of the supinator longus and becomes subcutaneous in the lower part of the forearm, to be distributed to the dorsum of the hand The posterior interosseous (or deep branch of radial) passes around the head of the radius and descends in the forearm between the deep and superficial muscles, supplying all the muscles of the forearm (Figs 24, 25) The terms in parentheses are inserted as an aid to orientation for those who think in B.N.A. terminology In what follows these terms will be supplied only when necessary for clearness

Motor Branches—In the upper part of the arm the musculospiral nerve supplies the triceps muscle and a branch to the anconeus In the bicipital groove in the lower part of the arm, it supplies the supinator longus muscle and the extensor carpi radialis longus As it passes around the head of the radius it gives off branches to the extensor carpi radialis brevis and the supinator brevis In its course through the forearm it supplies all the muscles on the back of the forearm

Sensory Branches—There are three sensory branches (1) a small branch given off high in the upper part of the arm to the pos-

tero-internal portion of the upper arm (2) the external cutaneous branch, given off in the middle of the arm and supplying a narrow strip of skin on the postero-external surface of the forearm, and (3) the radial nerve one of the terminal branches, which supplies the dorsum of the hand and, on the radial side, extends onto the fingers as far as the proximal interphalangeal joint.

Wristdrop.—The striking feature of paralysis in the region of distribution of the musculospiral nerve, because it is so evident on simple inspection, is wristdrop. In these cases there is some weakness of flexion of the fingers, as is seen in the attempt to close the hand. This is due not to any actual weakness of the muscles of flexion but to absence of the synergic action of their antagonists (the extensors) In order to have efficient closing of the fingers, the hand must be supported in partial hyperextension by the action of the extensors of the wrist.

Fig. 26.—Typical wristdrop from complete paralysis in the region of distribution of the musculospiral nerve (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

Injury Above Branches to Triceps Muscle.—Paralysis in the region of distribution of the musculospiral nerve above the branches to the triceps muscle will result in inability to extend the elbow (triceps) inability to extend the wrist (extensor carpi radialis longus and brevis and extensor carpi ulnaris) (Fig. 26) inability to extend the fingers (extensor digitorum communis) inability to extend the thumb (long and short extensor of the thumb and abductor pollicis longus) weakness in flexion of the elbow because of paralysis of the supinator longus (a powerful flexor of the elbow acting especially when the hand is midway between pronation and supina-

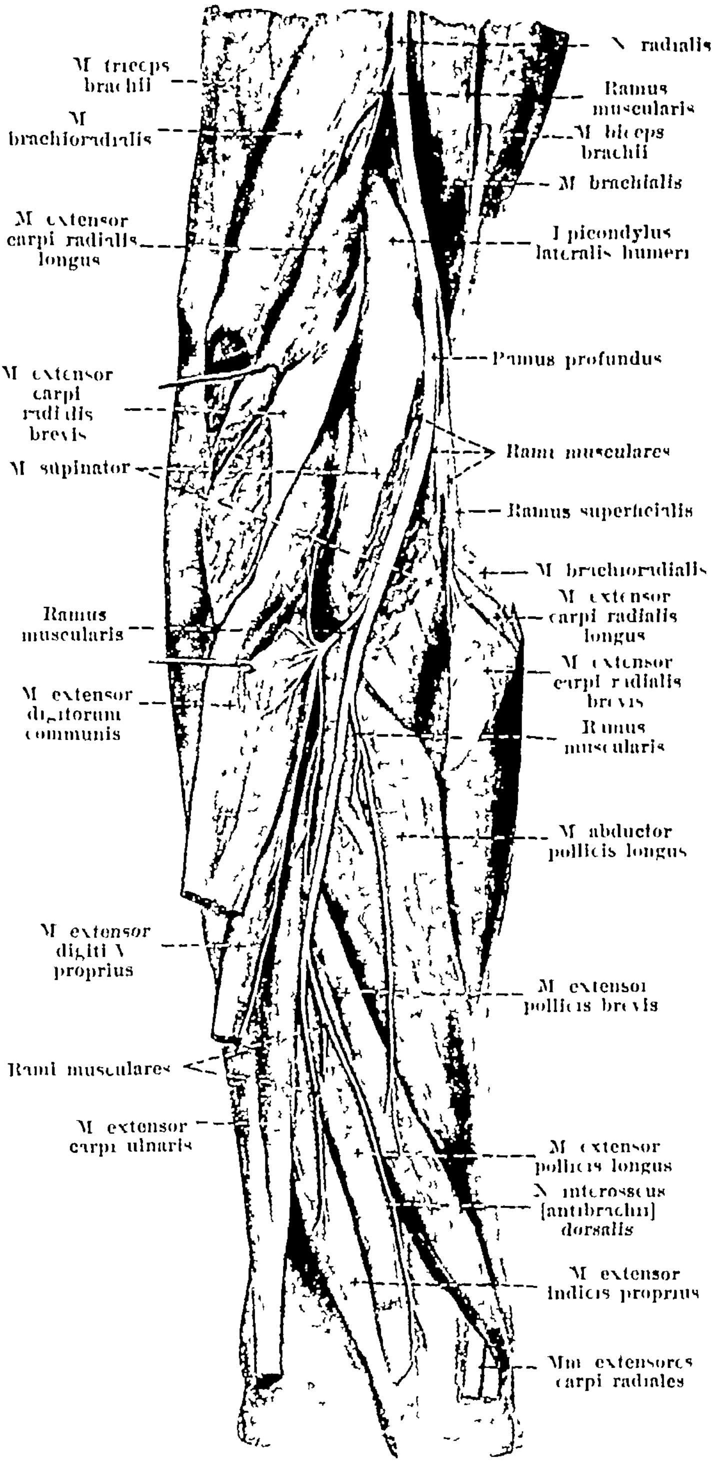

Fig 25—Muscle and nerves of the upper part of the right arm, viewed from behind and lateralward (Spalteholz Hand Atlas of Human Anatomy, Vol 3 J B Lippincott Co)

nerve is given off will give this anesthesia over the dorsum of the hand.

Injury above Supinator Longus Nerve.—The most common site of injury to the nerve is above the point of origin of the nerve to the supinator longus. It may result from fracture of the humerus or from the callus following a fracture, although the former is more frequent. It will give the same picture as that which has been described except that the triceps muscle and the triceps reflex are spared. The external cutaneous branch may or may not be affected.

Fig. 29.—Phases in regeneration of the musculospiral nerve. Beginning extension of the fingers but not of the thumb (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

If it is spared there will be no sensory loss, except over the dorsal aspect of the thumb.

Injury below Supinator Longus Nerve.—Injury below the supinator longus nerve will give essentially the picture of wristdrop. The nerve to the extensor carpi radialis longus arises just below that to the supinator longus and may also be spared in this type of lesion, either in whole or in part. If it is spared, some extension of the wrist will be possible on the radial side. That is, there will be some extension of the wrist associated with *abduction*, but contraction of the extensor carpi ulnaris is lost, as is extension of the fingers and

tion), and weakening of supination (supinator longus and brevis) There will be sensory loss in the dorsum of the hand. The triceps reflex also will be absent if the lesion affects the nerve high up, as in cases of crutch palsy (Figs 27, 28, 29)

Fig 27 —Position of hand in a case of paralysis in the region of distribution of the posterior interosseous nerve Extension of the wrist is possible but not of the fingers (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

Injury to Sensory Branch in Upper Arm —The small sensory branch in the upper part of the arm has no exclusive area of sensory supply Complete division of the nerve results in loss of cutaneous sensibility over the dorsal aspect of the hand (radial side) and thumb, and part of the proximal phalanges of the index and

Fig 28 —Paralysis in the region of distribution of the posterior interosseous nerve regeneration begun Extension of the wrist is seen, with incomplete extension of the second and third fingers This patient was bitten by her pet chow dog, one tooth penetrated the posterior interosseous nerve, another barely missed the ulnar nerve (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

middle fingers Occasionally there is some loss of sensation on the dorsum of the forearm, but usually the overlap from the musculocutaneous and internal cutaneous nerves suffices to prevent any definite zone of anesthesia in this region (Fig 30) Any lesion above the point where the external cutaneous branch of the musculospiral

nerve is given off will give this anesthesia over the dorsum of the hand.

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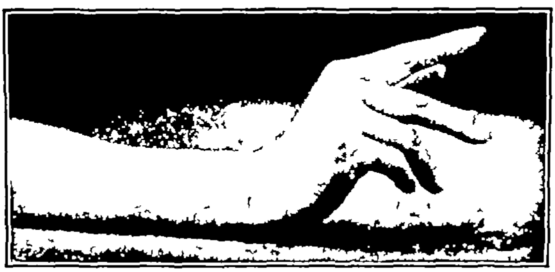
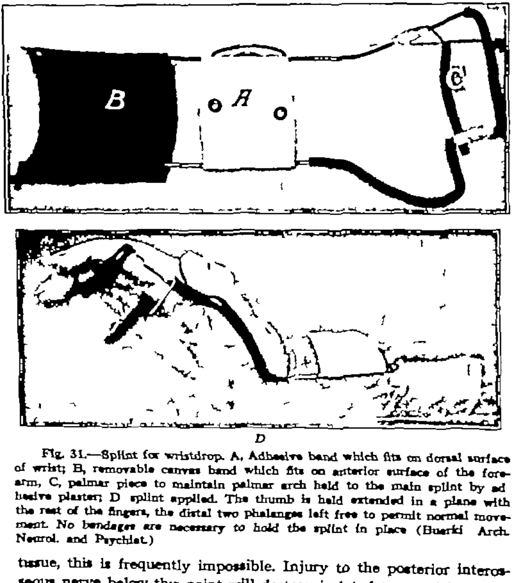


Fig 28 —Paralysis in the region of distribution of the posterior interosseous nerve regeneration begun Extension of the wrist is seen, with incomplete extension of the second and third fingers This patient was bitten by her pet chow dog, one tooth penetrated the posterior interosseous nerve, another barely missed the ulnar nerve (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons).

middle fingers Occasionally there is some loss of sensation on the dorsum of the forearm, but usually the overlap from the musculocutaneous and internal cutaneous nerves suffices to prevent any definite zone of anesthesia in this region (Fig 30) Any lesion above the point where the external cutaneous branch of the musculospiral

after formation of the posterior interosseous nerve it breaks up over the head of the radius into its terminal branches. If the injury is to the posterior interosseous nerve at this level, the subdivisions of the nerve are separately damaged. It is seldom possible to suture the nerve at this point since identification of the separate branches must be made. They must be sutured and, in the presence of scar



D

Fig. 31.—Splint for wristdrop. A, Adhesive band which fits on dorsal surface of wrist; B, removable canvas band which fits on anterior surface of the forearm, C, palmar piece to maintain palmar arch held to the main splint by adhesive plaster; D splint applied. The thumb is held extended in a plane with the rest of the fingers, the distal two phalanges left free to permit normal movement. No bandages are necessary to hold the splint in place (Buerki Arch. Neurol. and Psychiat.)

tissue, this is frequently impossible. Injury to the posterior interosseous nerve below this point will destroy isolated terminal branches of the nerve to the extensors of the fingers and thumb.

Extensive Injury.—If the damage to the musculospiral nerve is extensive and satisfactory suture and repair cannot be accomplished, *tendon transplantation* can be done and a fairly good functional hand obtained. However every attempt should be made first to repair

thumb. Sensory changes will be found over the dorsum of the first interspace and dorsum of the thumb

Injury in Forearm—Injury in the forearm will affect the radial and the posterior interosseous nerves which separate at the elbow. A little below the elbow a wound of the posterior interosseous will

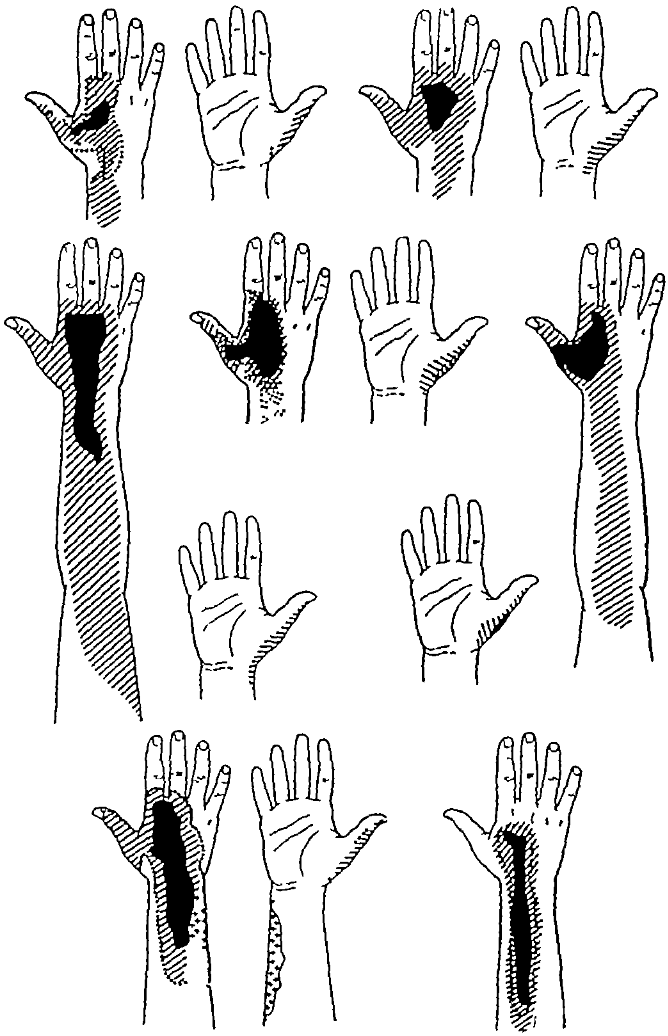


Fig 30—Patterns of sensory loss from lesions of the musculospiral nerve (Pollock and Davis Peripheral Nerve Injuries Paul B Hoeber, Inc.) Key Solid black, loss of pain, touch and temperature, diagonal lines, loss of touch, dots, loss of temperature, crosses, analgesia

spare the nerve to the short radial extensor In that case extension of the wrist on the radial side will be intact There will be paralysis of the ulnar extensor of the wrist, of the extensors of the fingers, and of the extensors of the thumb

Injury to Posterior Interosseous Nerve—Almost immediately

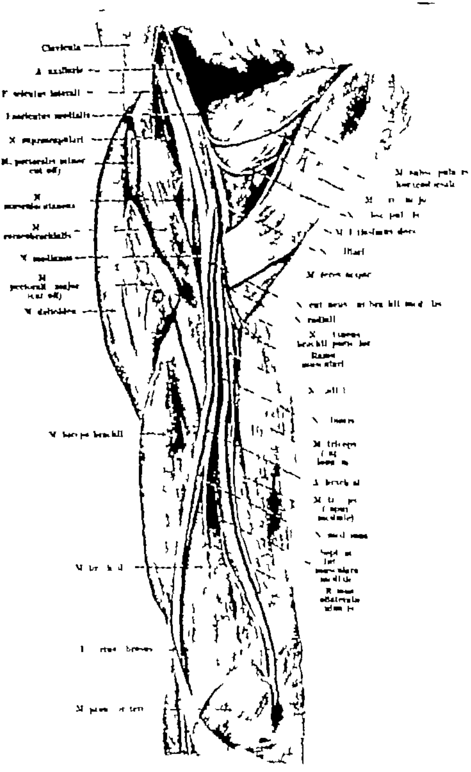


Fig. 32.—Nerves of the upper part of the right arm, medial view (Spalteholz: Hand Atlas of Human Anatomy Vol. 3 J B. Lippincott Co.)

the damaged nerve, reserving tendon transplantation for those instances in which the nerve cannot be repaired

Injuries Affecting Branches to Supinator Longus and Extensor Carpi Radialis Longus—Incomplete lesions of the nerve, where it lies on the anterolateral surface of the humerus, may affect the branches to the supinator longus and the extensor carpi radialis longus which lie in the dorsolateral portion of the cross-section of the nerve trunk As far as is known, the general topography as to muscular supply in a cross-section of the musculospiral nerve in this region is from ventral to dorsal laterally, supinator longus, radial extensors, mesially, ulnar extensor of the wrist and the extensors of the thumb and fingers, and the supinator brevis

Injury of the radial nerve may call for the device illustrated in Fig 31

Ulnar Nerve (Figs 32, 33)

Course and Distribution—The ulnar nerve arises from the inner (medial) cord of the brachial plexus along with the inner head of the median nerve In the upper part of the arm it lies on the inner side of the brachial artery and close to the median nerve In the lower part of the arm it bends away from the artery and passes to the back of the humerus, where it lies in the groove between the internal condyle of the humerus and the olecranon process In the forearm it passes through the flexor carpi ulnaris and runs beneath this muscle to the wrist Here it pierces the deep fascia and enters the hand At this level it gives off its two terminal branches, the superficial palmar branch, which is sensory, and the deep palmar branch, which is motor

Motor Branches—In the forearm the ulnar nerve supplies the flexor carpi ulnaris, and the ulnar half of the flexor digitorum profundus serving the fourth and fifth fingers In the hand it supplies the muscles of the hypothenar eminence, all the interossei, the two inner lumbricals and, in the thenar eminence, the adductor pollicis and the short head of the flexor pollicis brevis

Sensory Branches—The sensory supply is exclusively to the hand The superficial palmar branch supplies the skin over the inner part of the palm, as far as the wrist, the fifth finger, and half of the fourth finger (Fig 34)

Paralysis in Region of Distribution Effect on Wrist—Flexion of the wrist is impaired owing to loss of action of the flexor carpi ulnaris The hand is tilted to the radial side in flexion This loss is fairly compensated by the palmaris longus Paralysis of the muscles

can be detected by failure to feel the tendon contract at its point of insertion at the wrist.

EFFECT ON FINGERS.—Flexion of the fifth and fourth fingers is greatly impaired. Some flexion is possible through the flexor digitorum sublimis supplied by the median nerve. But flexion of the terminal

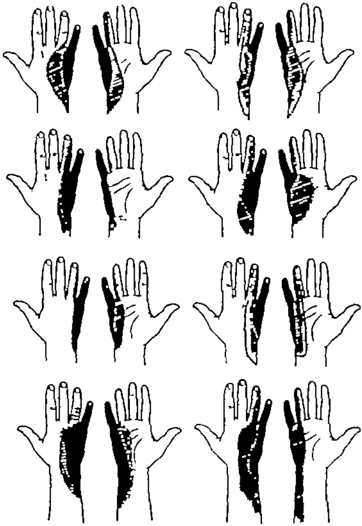


Fig. 34.—Types of loss of sensation in association with lesions of the ulnar nerve (Pollock and Davis Peripheral Nerve Injuries. Paul B. Hoeber Inc.) Key: S, hypesthesia; also, see Fig. 30

phalanges is impossible owing to paralysis of the portion of the flexor digitorum profundus destined for these fingers.

The normal function of the interossei is adduction and abduction of the fingers, flexion of the fingers at the metacarpophalangeal joints, and extension at the interphalangeal joints. Abduction and adduction of the fingers are lost. This should be tested on a flat sur

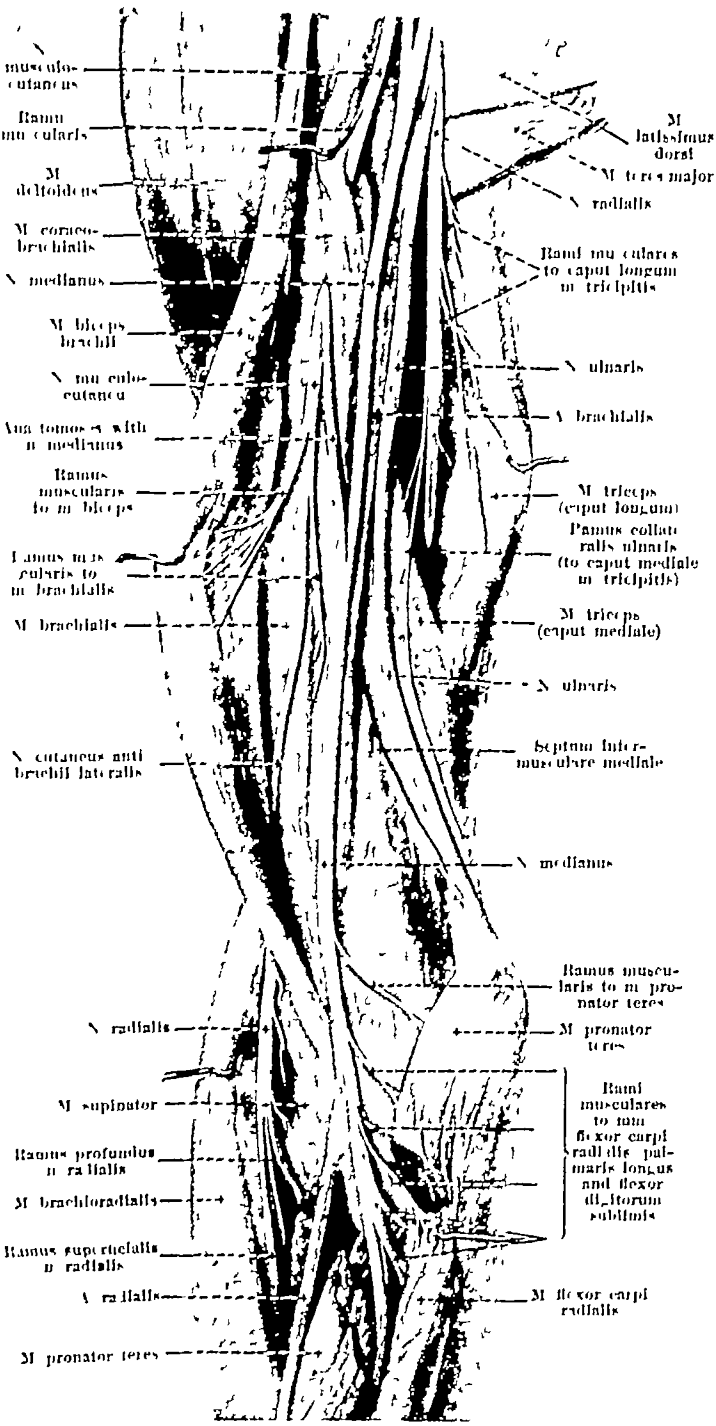


Fig 33 —Nerves of the upper part of the right arm viewed from in front (Spalteholz Atlas of Human Anatomy, Vol 3 J B Lippincott Co)

EPICRITIC AND PROTOPATHIC LOSSES.—Epicritic loss occurs over the sensory area that has been described. The area of epicritic loss

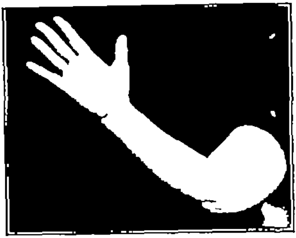


Fig. 37.—Paralysis in the region of the distribution of the ulnar nerve twenty-one years after fracture of the humeral condyles. Line of incision on hand nine months after transposition of ulnar nerve (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

for the ulnar nerve has very sharp and well-defined borders. The protopathic loss is considerably smaller and less constant.

Fig. 38.—Paralysis in the region of distribution of the ulnar nerve (same case as that represented in Fig. 37) one year after transposition, with beginning regeneration and return of ulnar function (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

INJURY BELOW ELBOW.—Injury below the elbow will produce the same symptoms, except for preservation of ulnar flexion of the wrist, and flexion of the terminal phalanges of the fifth and fourth fingers.

face, to avoid any confusion with the long flexors and extensors, which also have some action in adduction and abduction Hyperextension of the fingers at the metacarpophalangeal joints is found and is due to loss of action of the interossei, which flex these joints, and the unopposed action of the long extensors of the fingers Flexion at the

Fig 35 —Hand in a case of paralysis in the region of the distribution of the ulnar nerve Note the loss of contour of the hypothenar eminence and the position of the fourth and fifth fingers The thumb has fallen to the same plane as the metacarpal bones of the second to the fifth fingers (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

interphalangeal joints is due also to paralysis of the interossei which extend the phalanges and to the unopposed action of the flexors This hyperextension of the metacarpophalangeal joints and flexion of the interphalangeal joints are more marked in the fifth and fourth fingers than in the third and second fingers This difference is because of the sparing of one of the two outer lumbricals, which are supplied by the median nerve (Fig 35)

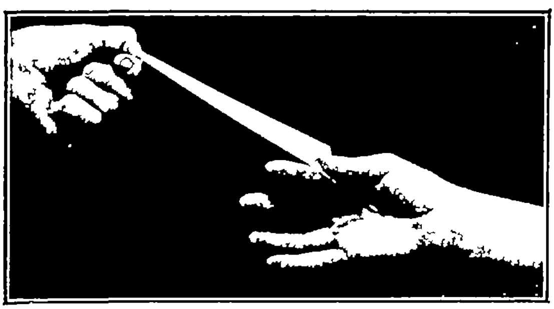


Fig 36 —Paralysis in the region of distribution of the ulnar nerve In the normal hand, paper can be grasped firmly in the first interspace In the presence of injuries of the ulnar nerve, the paper is held by flexion of the distal phalanx (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

Due to paralysis of the adductor pollicis, adduction of the thumb is lost (Fig 36) This movement also should be tested with the hand on a flat surface, to distinguish the condition from that produced by a somewhat similar action exerted by the long flexor of the thumb (Figs 37, 38)

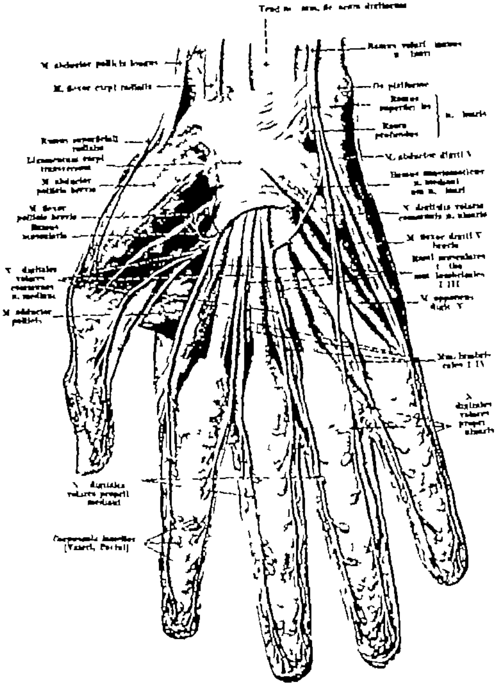


Fig. 39.—Nerves of the right palm (Spalteholz Hand Atlas of Human Anatomy Vol. 3 J B. Lippincott Co.)

of the hand, the distal two and a half phalanges of the middle and index fingers and the last two phalanges of the fourth finger (Fig. 42)

Paralysis in Region of Distribution.—Paralysis in the region of

INJURIES AT WRIST—In injuries at the wrist, the dorsal cutaneous branch having already been given off, sensory disturbance will be confined to the palm and the motor disturbances to the deep palmar branches

Topographic Anatomy—Incomplete lesions have shed some light on the topographic anatomy of the ulnar nerve In the cross-section of the nerve from within outward, the following arrangement apparently occurs (1) cutaneous branches and branches to the hypothenar eminence, (2) fibers to the interossei, (3) fibers to the adductor pollicis; (4) fibers to the flexor carpi ulnaris and the flexor digitorum profundus

Effect of Irritations—Irritations of the ulnar nerve are especially likely to lead to muscular fibrosis, contractures, and deformities It is in ulnar lesions that the anomalous "reflex contractures" of Babinski occur while, on the other hand, causalgia is uncommon in association with ulnar lesions

Median Nerve

Course and Distribution—The median nerve arises by two heads, one from the outer (lateral) and one from the inner (medial) cord of the brachial plexus The nerve descends along the lateral surface of the brachial artery, crossing it in the lower half of the arm. At the elbow it lies mesial to the brachial artery and beneath the bicipital fascia, on the brachialis anticus muscle Entering the forearm between the heads of the pronator radii teres, it runs down the forearm between the superficial and deep muscles, gradually shifting to the radial side. At the wrist it becomes almost subcutaneous, lying just beneath the tendon of the palmaris longus (Fig 39)

Motor Branches—The median nerve supplies all the muscles of the anterior surface of the forearm except the flexor carpi ulnaris and the ulnar portion of the flexor digitorum profundus, that is, it supplies the pronator radii teres, flexor carpi radialis, palmaris longus, flexor digitorum sublimis, outer heads of the flexor digitorum profundus and pronator quadratus

In the hand it supplies the muscles of the thenar eminence except the deep head of the flexor pollicis brevis, that is, the abductor pollicis brevis, opponens pollicis, and the superficial head of the flexor pollicis brevis It also supplies the two outer lumbricals (Figs 40, 41)

Sensory Branches—The sensory supply is exclusively to the hand On the palmar surface, this includes the radial half of the fourth finger, the middle and index fingers, the palmar surface of the thumb, and the corresponding areas of the palm, on the dorsum

slightest flexion accomplished by the interossei remains. Loss of this action is especially noticeable in the index finger

The terminal phalanx of the thumb cannot be flexed owing to loss of the action of the flexor pollicis longus and of the superficial head of the flexor pollicis brevis. Abduction of the thumb and opposition of the thumb are lost, due to paralysis of the abductor pollicis brevis and the opponens pollicis. Substitutions by other muscles may be confusing. In abduction the thumb should come straight out

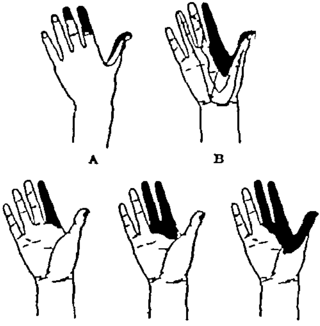


Fig. 42.—Sensory changes in injury to the median nerve. In A and B the dark area is the absolute loss included within the dotted line the affective forms are lost, and within the continuous line the discriminative forms; C, D and E, show various forms of absolute anesthesia in the presence of injuries to the median nerve (Stookey in Nelson's Loose-Leaf Surgery Vol. 2 Thomas Nelson and Sons)

in a plane at right angles to the palm. In opposition, the thumb rotates so that its palmar surface looks toward the palm. True opponens action is easily simulated. In true opponens position, the distal phalanx is brought into apposition with the distal phalanx of the fifth finger and both digits form a vertical arch over the palm.

Little deformity of the hand occurs even after division of the median nerve above the branches of the flexors. Many of the movements lost can be substituted by other movements and the disability is, therefore, not great. The loss of flexion of the terminal phalanx of the thumb and of the distal two phalanges of the index finger

distribution of the median nerve causes loss of active pronation However, due to the weight of the part, passive pronation may be found even though the pronator teres and pronator quadratus both have lost their innervation

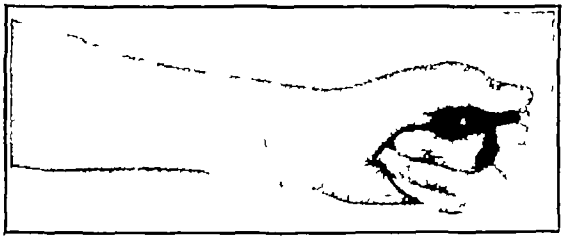


Fig 40—Position of hand in presence of paralysis in the region of distribution of the median nerve The index finger is semiflexed at the metacarpophalangeal joint. The interphalangeal joints are not flexed Flexion of the thumb is impossible (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

Flexion of the wrist is normally produced by the flexor carpi radialis and palmaris longus supplied by the median nerve With these paralyzed, some flexion of the wrist toward the ulnar side is still possible due to the action of the flexor carpi ulnaris Flexion of the fingers is normally produced as follows at the metacarpophalangeal joints by the interossei, at the proximal interphalangeal

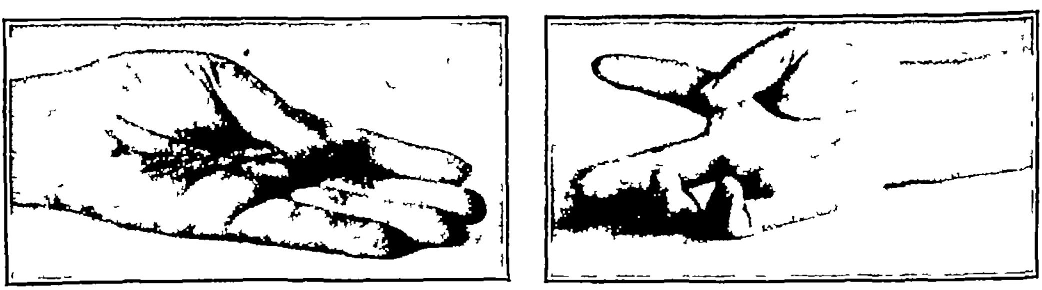


Fig 41—Injury to the median nerve Pseudo-opposition of thumb, paralysis of opponens pollicis muscle The thumb is adducted but not raised, as occurs in true opposition (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

joints by the flexor digitorum sublimis, at the distal interphalangeal joint by the flexor digitorum profundus To the fourth and fifth fingers, the flexor digitorum profundus, supplied by the ulnar nerve, is unaffected Thus considerable flexion remains but it is weaker than normal, owing to loss of the action of the flexor digitorum sublimis Since both flexor digitorum sublimis and flexor digitorum profundus, to the middle and index fingers, are paralyzed, only the

biceps shortly after its emergence, it then descends between the biceps and brachialis anticus to the elbow where it becomes the *external cutaneous nerve. Motor branches supply the* coracobrachialis, biceps, and part of the brachialis anticus, while the *sensory branches* supply a long area on the anteroposterior lateral aspect of the forearm that is, the preaxial border

Injury to the musculocutaneous nerve in the upper third of the arm results in paralysis of the muscles supplied, which are the chief flexors of the forearm (Fig. 43) Powerful flexion of the forearm, however is still possible through the action of the supinator longus. Supination of the arm, however is weak owing to loss of the supinator action of the biceps.

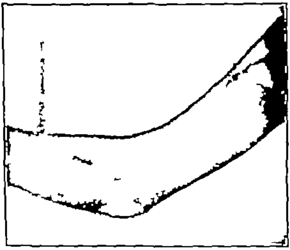


Fig. 43.—Injury to the musculocutaneous nerve, with paralysis of the biceps. Note loss of contour of biceps muscle failure to see biceps tendon, and marked hollow in front of elbow Belly of brachioradialis muscle is seen in act of flexion of forearm (Stookey in Nelson's Loose-Leaf Surgery Vol. 2 Thomas Nelson and Sons)

The sensory loss is ill-defined posteriorly where there is considerable overlapping with the musculospiral nerve. On the front of the forearm, where the area of sensory loss comes in contact with the internal cutaneous nerve, it is well defined.

Internal Cutaneous and Lesser Internal Cutaneous Nerves

The internal cutaneous and lesser internal cutaneous nerves are seldom affected alone. Usually either the median or ulnar or both, suffer at the same time. They arise from the inner (medial) cord of the brachial plexus and are purely sensory in function, supplying the inner surface of the arm and forearm that is, the postaxial border Injuries of these nerves will cause corresponding loss of cutaneous

as well as the loss of opposition of the thumb, will establish the diagnosis.

Injuries in the lower part of the forearm and wrist will involve only the small muscles of the thumb in the thenar eminence

Sensory Loss in Region of Distribution—Epicritic sensibility is lost over the area described It is sharply defined and constant. Protopathic loss is much smaller and less constant Because of the preservation of deep sensibility, care must be used to avoid eliciting deep sensibility when testing for epicritic sensibility

The pattern of the sensory disturbance following complete division of the nerve follows the normal distribution of the nerve as described above

Partial lesions would seem to indicate that the fibers for the *pronator teres, flexor carpi radialis, flexor pollicis longus,* and the muscles of the thenar eminence occupy the lateral part of the nerve The fibers for the flexors of the fingers are mesial The most severe forms of nerve irritation, especially the causalgias, are more common in association with partial lesions of the median nerve than in association with injuries of any other nerve

Median and Ulnar Nerves

Combined involvement of these two nerves is of very frequent occurrence because of the close association of the nerves in the upper part of the arm and their proximity in the lower part The sensory loss is that of the combined sensory distribution of the two nerves, with a large area of absolute loss due to loss of the combined area of nerve overlap In cases of complete paralysis of all the muscles supplied by both nerves, flexion of the wrist and fingers and pronation of the forearm are gone The action of all the small muscles of the thenar eminence, hypothenar eminence, interossei, and lumbricals is also completely lost. Adduction and abduction of the fingers and opposition of the thumb and fingers are lost. There is marked wasting of the palm Injuries of the median and ulnar nerves combined are extremely disabling due to the marked periarticular changes at the metacarpophalangeal and interphalangeal joints, with fixation of these joints

Musculocutaneous Nerve

The musculocutaneous nerve arises with the outer head of the median, from the outer (lateral) cord of the brachial plexus It runs with the median in the upper third of the arm, then passes through the coracobrachialis muscle, giving off its muscular branches to the

biceps shortly after its emergence It then descends between the biceps and brachialis anticus to the elbow where it becomes the external cutaneous nerve. *Motor branches* supply the coracobrachialis, biceps, and part of the brachialis anticus, while the *sensory branches* supply a long area on the anteroposterior lateral aspect of the forearm that is, the preaxial border

Injury to the musculocutaneous nerve in the upper third of the arm results in paralysis of the muscles supplied, which are the chief flexors of the forearm (Fig. 43) Powerful flexion of the forearm, however is still possible through the action of the supinator longus. Supination of the arm, however is weak owing to loss of the supinator action of the biceps.

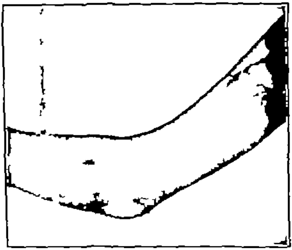


Fig. 43.—Injury to the musculocutaneous nerve, with paralysis of the biceps. Note loss of contour of biceps muscle, failure to see biceps tendon, and marked hollow in front of elbow Belly of brachioradialis muscle is seen in act of flexion of forearm (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

The sensory loss is ill-defined posteriorly where there is considerable overlapping with the musculospiral nerve. On the front of the forearm, where the area of sensory loss comes in contact with the internal cutaneous nerve, it is well defined.

Internal Cutaneous and Lesser Internal Cutaneous Nerves

The internal cutaneous and lesser internal cutaneous nerves are seldom affected alone. Usually either the median or ulnar or both, suffer at the same time. They arise from the inner (medial) cord of the brachial plexus and are purely sensory in function, supplying the inner surface of the arm and forearm that is, the postaxial border Injuries of these nerves will cause corresponding loss of cutaneous

sensation They seldom require surgical measures unless painful nerve ends have formed

Circumflex Nerve

The circumflex nerve arises from the posterior cord of the brachial plexus and passes through the quadrilateral space, to wind around the posterior surface of the neck of the humerus, entering the deltoid muscle

Motor branches supply the deltoid and teres minor muscles *Sensory branches* supply the skin on the upper lateral aspect of the arm and shoulder

Injury to the circumflex nerve results in paralysis of the deltoid and teres minor muscles Abduction of the arm is impossible Slight substitution movements are possible through the supraspinatus There is a sensory loss over the region described Isolated injury to the circumflex nerve is exceedingly rare in association with war wounds Paralysis of the deltoid muscle is commonly seen in the presence of lesions of the brachial plexus, especially paralysis of the Duchenne-Erb type

Long Thoracic Nerve

The long thoracic nerve arises from the fifth, sixth, and seventh cervical roots, close to the intervertebral foramina It pierces the scalenus medius muscle as two trunks, descends along the side of the neck behind the cords of the brachial plexus, and enters the axilla between the superior edge of the serratus anterior and the axillary artery It then continues its downward course over the axillary surface of the serratus, to the slips of which it is distributed.

Injury to the long thoracic nerve results in paralysis of the serratus anterior muscle, preventing fixation of the scapula This interferes with weight carrying and also with elevation of the arm at the shoulder, especially abduction. "Winging" of the scapula is characteristic of lesions of this nerve (Fig 44)

Brachial Plexus

The brachial plexus is formed by the anterior primary divisions of the fifth, sixth, seventh, and eighth cervical nerves, and the first thoracic nerve These nerves appear in the posterior triangle of the neck. After entering the posterior triangle, the fifth and sixth roots unite, the seventh remains alone, and the eighth cervical and first thoracic unite to form the three primary cords Each of these cords then divides into an anterior and posterior portion The anterior

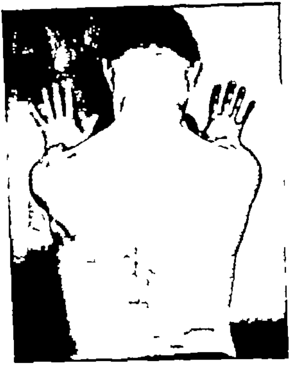


Fig. 44.—Paralysis of the serratus anterior due to injury of the long thoracic nerve, showing "winging" of the scapula.

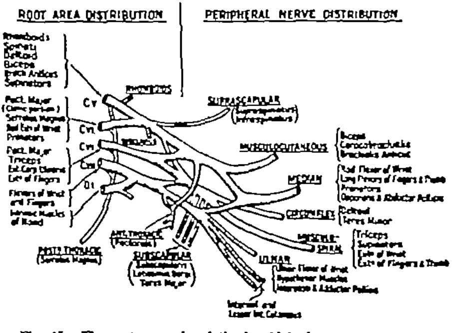
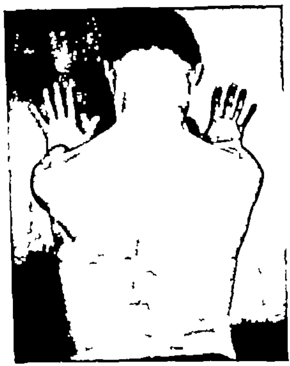


Fig. 45.—The motor supply of the brachial plexus, showing both its root area distribution and its peripheral nerve distribution (U. S. A. Manual of Neurosurgery)



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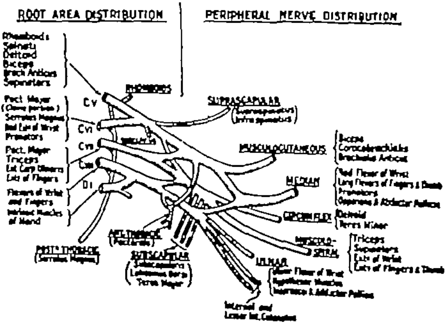

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as a rule, to the formation of two or more nerves. If the artery is injured in addition to the nerves, ischemic paralysis may result.

Certain nerves are given off high up in the plexus, involvement of which in an injury may aid in localization of the lesion. These are the nerves to the rhomboid muscles, from the fifth and sixth roots and the long thoracic to the serratus anterior from the fifth, sixth, and seventh roots.

Lesions of the nerve roots and primary cords of the brachial plexus produce symptoms and signs which, in their distribution, both

Fig. 47—Injury of brachial plexus of an adult. Total avulsion of the brachial plexus. Note the marked atrophy of the musculature of the shoulder girdle as well as the musculature of the arm (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

motor and sensory are segmental in type. They give rise to two different syndromes that of the upper part of the cord, or the Duchenne-Erb syndrome, and that of the lower part of the cord, or the Duchenne-Aran (Klumpke) syndrome.

The Duchenne-Erb Syndrome—This results essentially from a lesion of the anterior primary division of the fifth and sixth cervical nerves. The muscles involved are those paralyzed in the so-called birth palsies the deltoid, biceps, brachialis anticus, and supinator

divisions of the fifth, sixth, and seventh cervical, and first thoracic unite to form the inner (medial) cord, and the posterior divisions combine to form the posterior cord The cords then break up into the nerves of distribution (Figs 45, 46).

Involvement in Injuries—Injuries of the brachial plexus (Fig 47) are relatively uncommon, possibly because coincidental injuries to great vessels, in association with severe wounds of the neck, clavicle, and shoulder frequently prove to be fatal. Hence, damage to the brachial

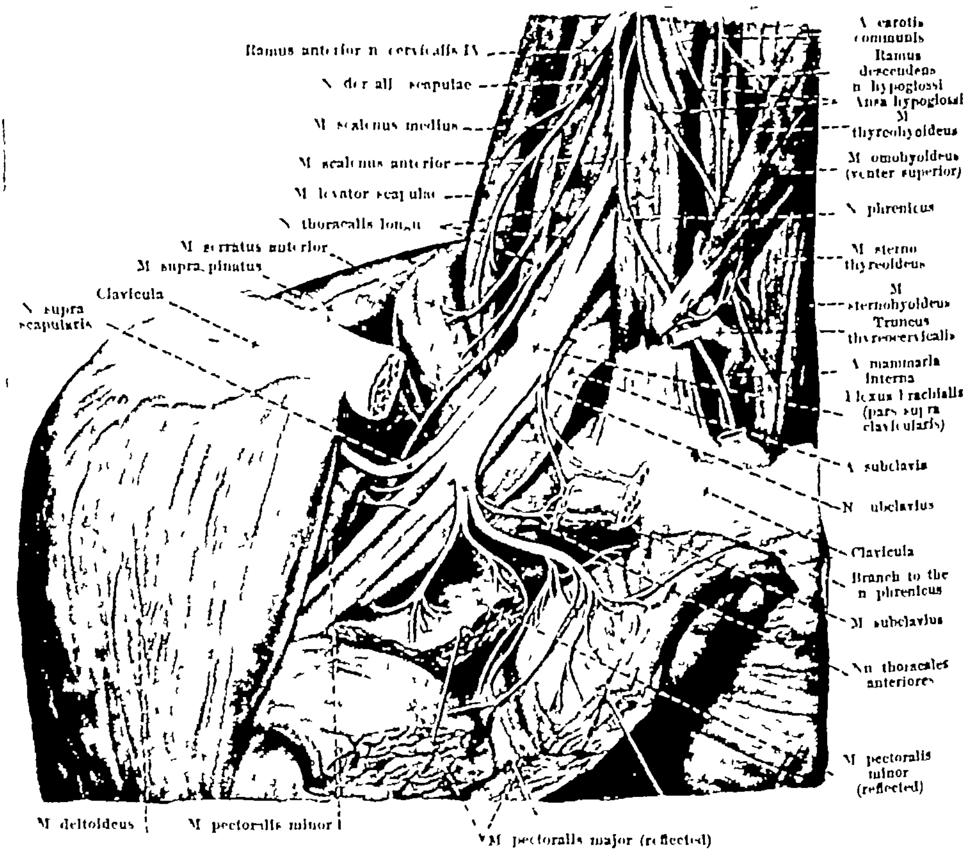

Fig 46—Right plexus brachialis with its short branches, viewed from in front (Spalteholz Hand Atlas of Human Anatomy, Vol 3 J B Lippincott Co)

plexus does not appear among the later statistics of nerve injuries In the statistics available such damage represents only about 5 per cent of the nerve injuries Extensive wounds of the shoulder girdle often result in the tearing of muscles and tendons, complicating the nerve lesion Involvement of the secondary cords of the plexus often follows dislocation of the shoulder and attempts to reduce it. In these cases the distribution of the paralysis is in the domain of one or more peripheral nerves, since the secondary cords contribute,

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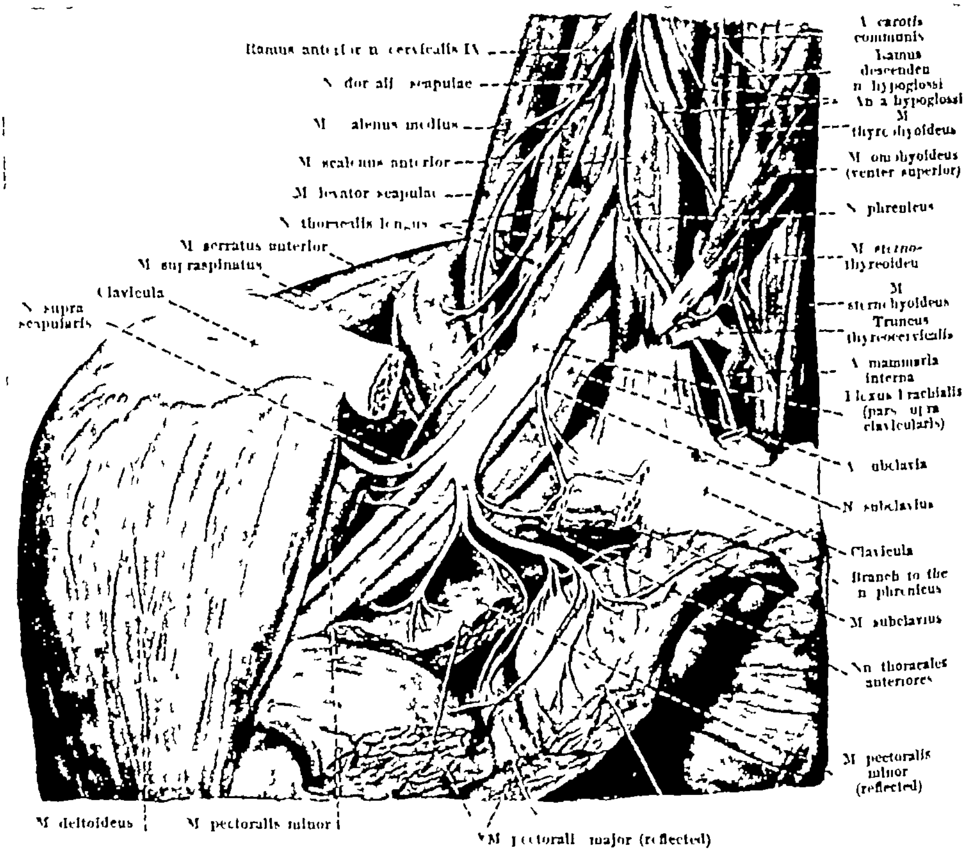

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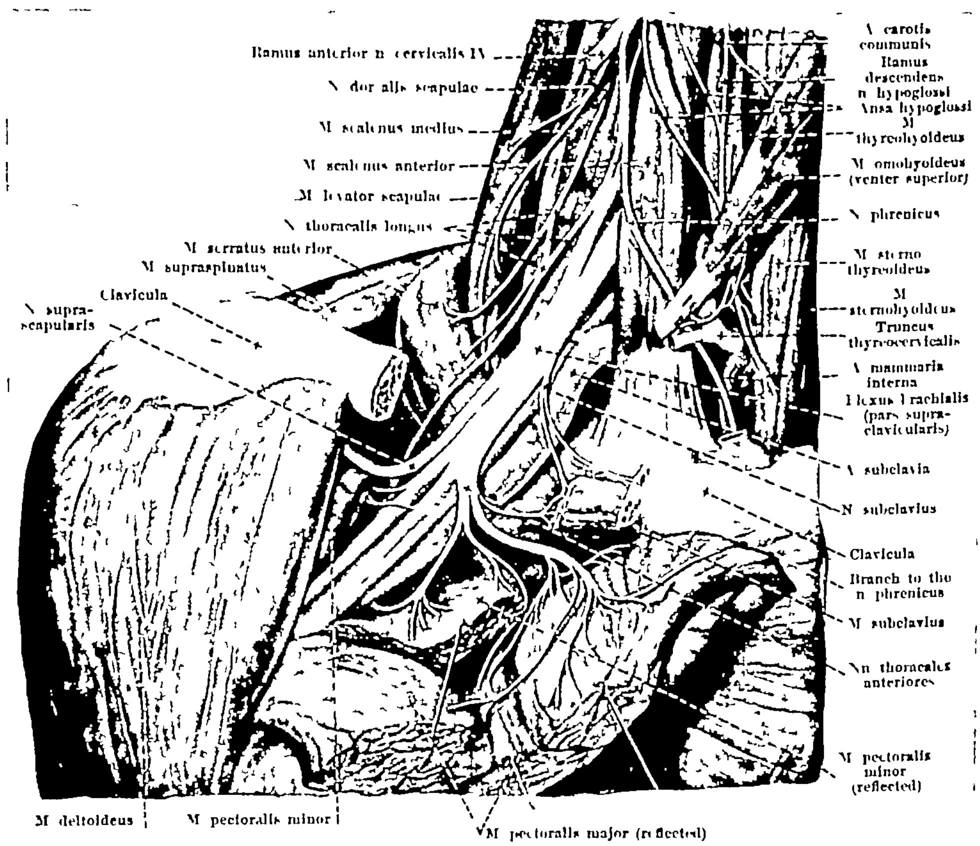

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does not dilate when shaded (paralysis of the dilator pupillae) drooping of the eyelid (paralysis of the smooth muscle fibers in the levator palpebrae) sinking in of the eyeball (enophthalmos) and narrowing of the palpebral fissure (paralysis of Müller's orbital muscle) There may be temporary reddening of the face, neck, and arm, and vasodilation due to paralysis of the vasoconstrictors as well as loss of sweating on the affected side of the face and upper extremity

Irritation of Cervical Sympathetic Nerves.—Irritation of the cervical sympathetic nerves produces dilatation of the pupil, widening of the palpebral fissure and exophthalmos. This irritation of the cervical sympathetic nerves is rarely observed after injuries of nerves.

Fig. 49.—Injury to secondary outer cords of brachial plexus with paralysis of the musculocutaneous and median nerves. Note loss of contour of biceps muscle and position of thumb (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

Lesions of Secondary Cords.—Lesions of the secondary cords give rise to symptoms and signs having the same type of distribution, both sensory and motor as lesions of the peripheral nerves. They differ however in that the muscles paralyzed are served by two, or parts of two, peripheral nerves. For instance, a lesion of the mesial cord will injure a part of the median nerve plus the ulnar nerve, whereas a lesion of the lateral cord will injure part of the median nerve plus the musculocutaneous.

Lesions of the *mesial secondary cord* result in paralysis of all the intrinsic muscles of the hand and of some of the flexors of the wrist and fingers, especially on the ulnar side. Loss of sensation along the inner side of the arm and forearm is a result of involvement of the internal cutaneous and lesser internal cutaneous nerves. There is no involvement of the cervical sympathetic nerves, as the white rami

longus and, in addition, there is some involvement of the flexors of the wrist and fingers (Fig 48) There is a more or less well-defined area of hypesthesia or anesthesia over the sensory distribution of the fifth and sixth cervical roots Owing to the overlap of adjacent roots, however, this is variable in extent.

The Duchenne-Aran Syndrome—This results from a lesion of the eighth cervical and first thoracic roots or of their combined primary cord. Injury results in paralysis of nearly all the small muscles of the hand, with the exception of the superficial muscles of

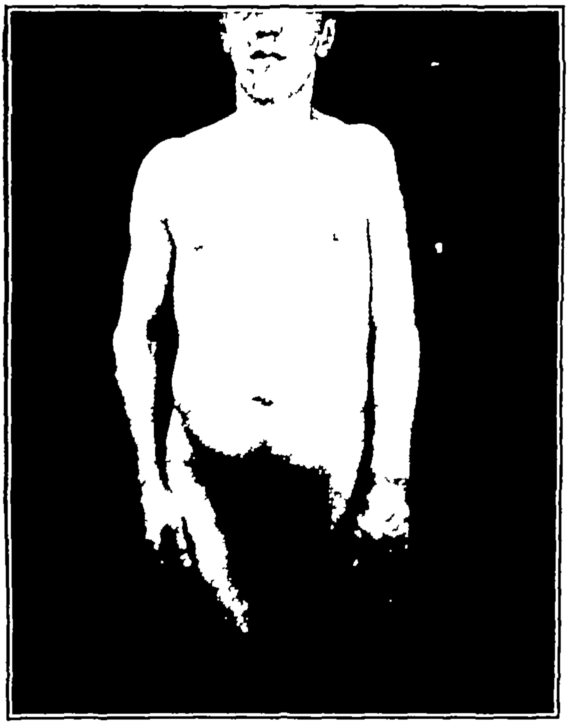

Fig. 48—Injury of brachial plexus of an adult involving the fifth, sixth, and seventh cervical roots of the left side The eighth cervical and first thoracic nerves have escaped injury (Stookey in Nelson's Loose-Leaf Surgery, Vol. 2 Thomas Nelson and Sons)

the thenar eminence and the flexors of the wrist and fingers The sensory disturbances in association with lesions of the first thoracic root are much better defined than those in association with lesions of the eighth cervical root and are confined to the inner aspect of the arm, forearm, and hand, that is, they are in the root distribution of the eighth cervical and first thoracic nerves Oculopupillary symptoms accompany this lesion, as the sympathetic nerves for the superior cervical ganglion leave the cord through the eighth cervical and first thoracic roots Injury of these fibers results in a small pupil which

does not dilate when shaded (paralysis of the dilator pupillae) drooping of the eyelid (paralysis of the smooth muscle fibers in the levator palpebrae) sinking in of the eyeball (enophthalmos) and narrowing of the palpebral fissure (paralysis of Müller's orbital muscle) There may be temporary reddening of the face, neck, and arm, and vasodilation due to paralysis of the vasoconstrictors as well as loss of sweating on the affected side of the face and upper extremity

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Lesions of the *mesial secondary cord* result in paralysis of all the intrinsic muscles of the hand and of some of the flexors of the wrist and fingers, especially on the ulnar side. Loss of sensation along the inner side of the arm and forearm is a result of involvement of the internal cutaneous and lesser internal cutaneous nerves. There is no involvement of the cervical sympathetic nerves, as the white *rami*

communicantes have already left the nerve trunks to join the sympathetic cord.

Lesions of the *lateral secondary cord* result in paralysis of muscles supplied by the musculocutaneous and the outer head of the median nerves. the biceps, coracobrachialis, brachialis anticus, and flexors of the fingers and wrist. There is anesthesia along the outer aspect of the forearm (Fig 49)

Lesions of the *posterior secondary cord* produce paralysis of the biceps, deltoid, and extensors of the wrist and fingers

Cervical Plexus

The cervical plexus is formed from the anterior primary divisions of the first four cervical nerves From the plexus arise *sensory nerves* distributed to the skin of part of the head, neck, and shoulders (lesser occipital, great auricular, and descending cervical nerves)

The chief *muscular branch* is the phrenic nerve, which arises mainly from the fourth cervical nerve, descends on the scalenus anterior muscle, enters the thorax, and is distributed to the diaphragm Paralysis in the region of distribution of the phrenic nerve results in loss of active movement of the diaphragm on the side of the injury The costal angle is usually more obtuse on the side of the paralysis

Sciatic Nerve: Peroneal and Tibial Divisions

These comprise the two main nerves of the sacral plexus, bound together by an investing sheath which contains, in addition to the common peroneal and tibial nerves, a subordinate branch of each, namely, the nerve to the hamstring muscles, from the tibial nerve, and the nerve to the short head of the biceps femoris muscle, from the peroneal nerve A thick band about ½ inch (1 27 cm) in breadth is formed, consisting, from medial to lateral, of nerves to the hamstring muscles· namely, the tibial nerve, the common peroneal nerve, and the nerve to the short head of the biceps muscle

Course and Distribution. SCIATIC NERVE—The sciatic nerve extends through the buttock into the back of the thigh. Forming a continuation of the sacral plexus, it enters the buttock by passing through the greater sciatic foramen, between the piriformis and superior gemellus muscles Concealed by the gluteus maximus muscle, it passes into the thigh, accompanied by the inferior gluteal artery and the arteria comitans nervi ischiadici. It lies between the greater trochanter of the femur and the tuberosity of the ischium and enters the thigh beneath the gluteus maximus muscle At that spot it is comparatively superficial. In the thigh it is placed on the adductor magnus

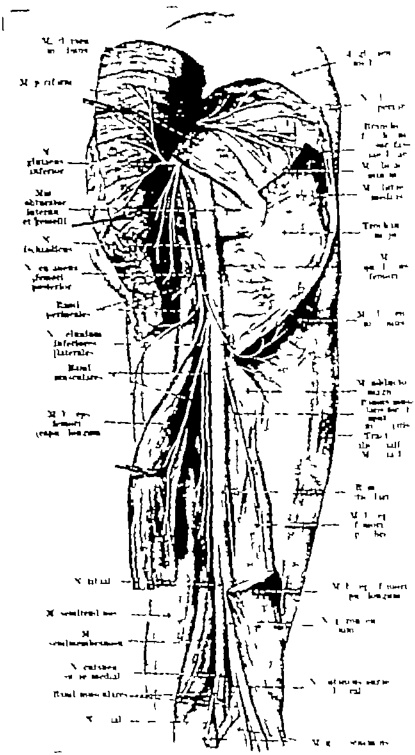

Fig. 50.—Nerves of the right thigh, viewed from behind (Spalteholz: Hand Atlas of Human Anatomy Vol. 3. J. B. Lippincott Co.)

muscle, anterior to the hamstring muscles, and it terminates at a variable point by dividing into the tibial and common peroneal nerves As already has been stated, these two nerves may be separate from their origins and their separation may occur at any point between the greater sciatic foramen and the proximal part of the popliteal fossa (Fig 50)

THE COMMON PERONEAL NERVE—This nerve is concealed at first by the biceps muscle Following the tendon of that muscle, the nerve passes obliquely through the proximal and lateral parts of the popliteal fossa and over the lateral head of the gastrocnemius muscle to the posterior aspect of the head of the fibula In the distal part of its course it is superficial but at its termination it is covered by the peroneus longus muscle The terminal branches of the common peroneal nerve are three the recurrent tibial, the deep peroneal, and the superficial peroneal They arise just distal to the head of the fibula (Fig 51)

DEEP PERONEAL NERVE—This nerve passes obliquely, distally, under cover of the peroneus longus, extensor digitorum longus, and extensor hallucis longus muscles, to the front of the leg In its course it is deeply placed on the interosseous membrane and the distal part of the tibia, in company with the anterior tibial artery Collateral branches are given off to the muscles between which the deep peroneal nerve passes, namely, the tibialis anterior, the extensor hallucis longus, the extensor digitorum longus, and the peroneus tertius

SUPERFICIAL PERONEAL NERVE—This nerve lies in a sheath in the intermuscular septum, between the peronei and the extensor digitorum longus, it proceeds distally in front of the fibula to the distal third of the leg, where it pierces the deep fascia in two branches, medial and lateral Collateral muscular branches are distributed to the peroneus longus and peroneus brevis, as the nerve lies in relation to these muscles Terminal cutaneous branches go to the medial and lateral aspects of the leg

TIBIAL NERVE—The tibial nerve, at the bifurcation of the sciatic nerve, passes onward through the popliteal fossa and the back of the leg In the popliteal fossa it is concealed at first by the semimembranous and the other hamstring muscles It passes to the medial side of the popliteal vessels and is thereafter found on the popliteus muscle, under cover of the gastrocnemius and plantaris In the back of the leg, from the distal border of the popliteus muscle to the ankle, the tibial nerve lies on the tibialis posterior muscle and the tibia and, along with the posterior tibial vessels, occupies a sheath in the intermus-

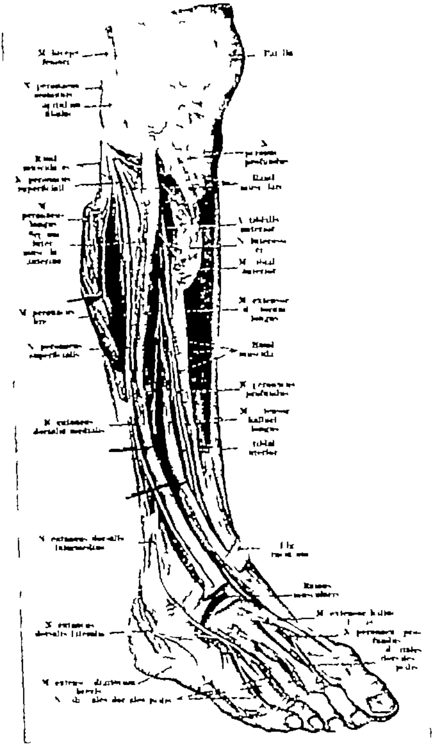

Fig. 51.—Nerves of the right leg from in front and lateralward (Spalteholz: Hand Atlas of Human Anatomy Vol. 3. J. B. Lippincott Co.)

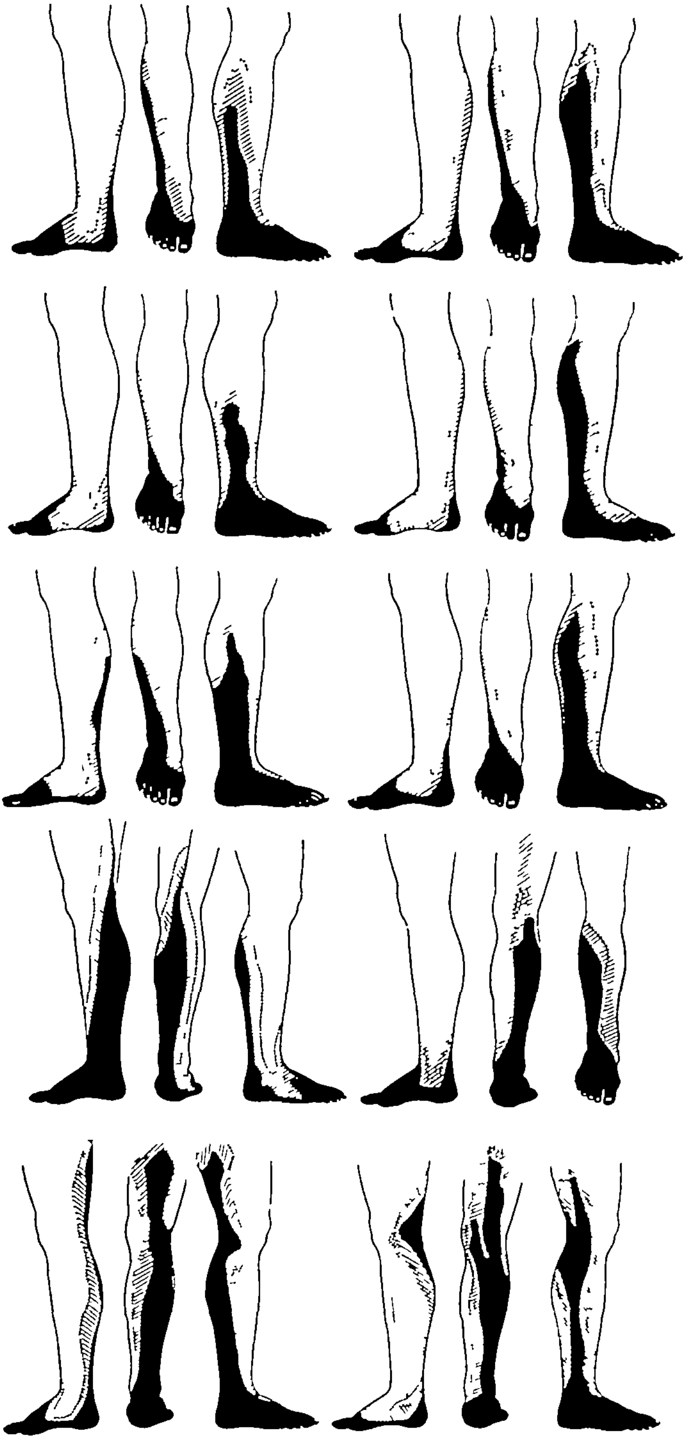

Fig 52—Sensory loss in association with lesions of the sciatic nerve (Pollock and Davis Peripheral Nerve Injuries Paul B Hoeber, Inc) Key See Fig 30

cular septum separating the superficial and deep muscles of the back of the leg. It terminates under cover of the internal annular (laciniate) ligament by dividing into the lateral and medial plantar nerves. *Muscular branches* arising in the popliteal fossa proximal to the knee joint include nerves for the two heads of the gastrocnemius and for the plantaris. These branches enter the muscles at the borders of the popliteal fossa. A nerve for the soleus muscle enters the superficial surface of the muscle A nerve for the popliteus muscle passes over the surface of that muscle and, after winding around its distal border supplies it on its deep (anterior) surface. As this nerve passes below the popliteus muscle it supplies branches to the tibialis posterior In the back of the leg, distal to the knee joint, branches serve the flexor digitorum longus and flexor hallucis longus. The terminal branches of the tibial nerve are the medial and lateral plantar nerves, which supply the plantar muscles of the foot and which register sensation over the plantar surfaces of the foot and the dorsal surfaces of the terminal phalanges.

Injury to Peroneal Nerves.—Injury to the peroneal nerves results in loss of dorsal flexion, with footdrop, due to paralysis of the tibialis anterior extensor digitorum longus, and extensor hallucis longus loss of abduction or elevation of the lateral border of the foot, due to loss of action of the tibialis anterior and peroneus longus and brevis, and weakness of adduction of the foot due to paralysis of the tibialis anterior For the same reason the inner arch of the foot is weakened. Cutaneous sensibility is lost over the antero-external aspect of the leg and dorsum of the foot (Fig. 52)

DEEP PERONEAL NERVE.—Injury to the deep peroneal nerve occurs with wounds in the front of the leg. Complete division results in footdrop, with contracture of the Achilles tendon. Sensory disturbances are found on the adjacent surfaces of the first and second toes. Wounds low in the leg may involve only the fibers for the extensor hallucis longus and extensor digitorum brevis (Fig. 53)

SUPERFICIAL PERONEAL NERVE.—Injury to the superficial peroneal nerve occurs with wounds in the lateral aspect of the leg, causing paralysis of the peronei. Eversion of the foot is impossible Cutaneous sensibility is lost over the anterolateral aspect of the leg and dorsum of the foot but the lateral aspect of the foot, supplied by the external saphenous nerve, is spared. Injury to the nerve below the point of origin of the nerves to the peronei will give only sensory disturbances.

Injury to Tibial Nerve.—Injury to the tibial nerve results in paralysis of the gastrocnemius, soleus, plantaris, tibialis posterior flexor hallucis longus, and flexor digitorum longus muscles, as well as of the

plantar muscles of the foot. There is loss of plantar flexion of the ankle due to paralysis of the gastrocnemius and soleus muscles, and loss of flexion of the toes due to paralysis of the flexor digitorum longus, flexor hallucis longus, and flexor digitorum brevis Adduction of the foot is weak, due to paralysis of the tibialis posterior, but is not lost, since in walking there is no spring to the step, as the patient cannot force his heel from the ground. There is loss of cutaneous sensibility over the whole sole of the foot, back of the heel, and outer surface of the foot.

Injury to the tibial nerve somewhat distal to the border of the popliteal muscle will spare the gastrocnemius and soleus muscles The flexor digitorum longus and the flexor hallucis longus and the small

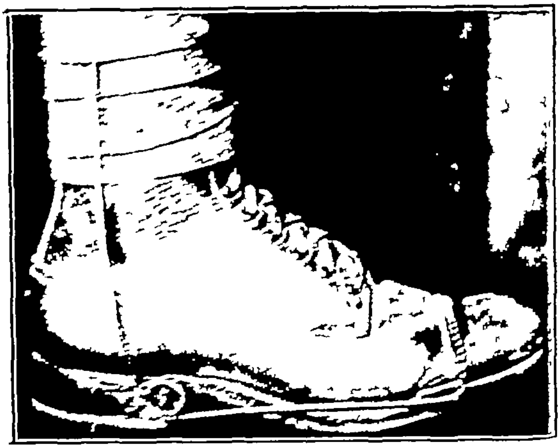

Fig. 53.—Splint for footdrop This splint is made of No 11 spring steel wire, held to the shoe with four pieces of piano wire and to the leg by a canvas band passing around the calf, between the two wires (Buerki: Arch. Neurol. and Psychiat.).

muscles of the plantar surface of the foot, however, will be affected, but this impairment may be overlooked unless it is sought.

Complete Division.—Complete division of the great sciatic nerve will give a combination of the symptoms of division of the tibial and peroneal nerves. All movements of the foot and toes are lost. If the nerve is divided at the level of the middle of the thigh, the semitendinosus may escape, as its nerve is given off very high. This will permit weak flexion of the knee. Slight flexion of the knee is also possible through the gracilis muscle, supplied by the obturator nerve There is extensive loss of sensibility below the knee, the inner surface of the leg (internal saphenous) alone escaping.

Irritations and Partial Syndromes.—Irritating lesions, with marked vasomotor and trophic disturbances, are common. Injuries of

the sciatic trunk and of the median nerve are the most frequent sources of causalgia. Partial syndromes are frequent, owing to the size of the nerve. The peroneal and tibial nerves, though bound together are really separate nerves well up in the thigh. In injuries of the sciatic trunk the peroneal division is much more likely to suffer than the tibial division. This part of the sciatic nerve lies more superficial than the tibial, owing to the fact that the sciatic is somewhat rotated.

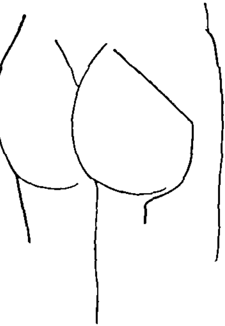

Fig. 54—Line of incision for exposure of the sciatic nerve at the sacro-sciatic notch and in its upper third (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

Small Sciatic Nerve

The small sciatic nerve arises from the first, second, and third sacral roots. It leaves the pelvis with the great sciatic and descends in the back of the thigh, buttock, and perineum (Figs. 54 55)

Anterior Crural (Femoral) Nerve

The anterior crural nerve arises from the lumbar plexus. It crosses the iliac fossa and enters the thigh beneath the inguinal ligament, lateral to the great vessels. Under the inguinal ligament it divides into its several branches to the muscles and skin of the thigh. One branch of the anterior crural nerve, namely the *internal saphenous nerve*, continues on down the inner side of the leg and foot.

The anterior crural nerve supplies the quadriceps extensor and

plantar muscles of the foot There is loss of plantar flexion of the ankle due to paralysis of the gastrocnemius and soleus muscles, and loss of flexion of the toes due to paralysis of the flexor digitorum longus, flexor hallucis longus, and flexor digitorum brevis. Adduction of the foot is weak, due to paralysis of the tibialis posterior, but is not lost, since in walking there is no spring to the step, as the patient cannot force his heel from the ground There is loss of cutaneous sensibility over the whole sole of the foot, back of the heel, and outer surface of the foot.

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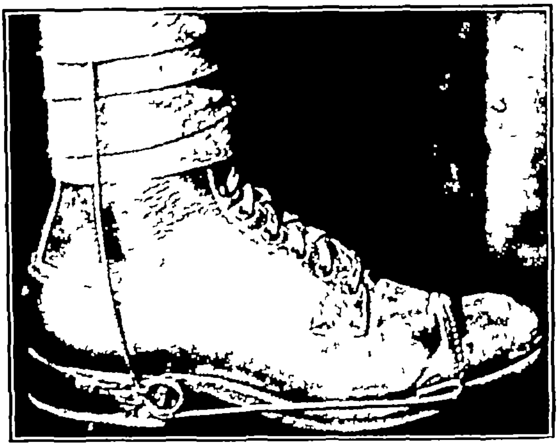

Fig 53—Splint for footdrop This splint is made of No 11 spring steel wire, held to the shoe with four pieces of piano wire and to the leg by a canvas band passing around the calf, between the two wires (Buerki Arch Neurol. and Psychiat.)

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Irritations and Partial Syndromes—Irritating lesions, with marked vasomotor and trophic disturbances, are common. Injuries of

the field, often cause death. Complete division can occur only in the pelvis or beneath the inguinal ligament. In the upper part of the thigh the nerve already has broken up into its several branches and injury will affect only a few of these. The chief symptom of division of the anterior crural nerve is loss of extension of the leg due to paralysis of the quadriceps extensor muscle.

Loss or impairment of cutaneous sensibility over the antero-internal aspect of the thigh, and loss of cutaneous sensibility over the inner aspect of the knee, leg, and foot follow section of the anterior crural nerve.

The *internal saphenous nerve* may be injured alone in the thigh or leg. Division will result in loss of cutaneous sensibility over the inner aspect of the knee, leg and foot.

Obturator Nerve

The obturator nerve arises from the lumbar plexus. It crosses the brim of the pelvis and enters the thigh by the obturator foramen. It is the motor nerve for the adductors of the thigh and for the gracilis muscle and it supplies sensation over a small area on the lower inner aspect of the thigh.

Complete division of the nerve results in loss of power in adduction of the thigh. The loss is not complete, as some fibers to the adductors arise from the anterior crural and sciatic nerves. There is generally no loss of sensation, owing to overlapping with adjacent cutaneous nerves.

External Cutaneous Nerve

The external cutaneous nerve arises from the lumbar plexus. It crosses the pelvis high up and enters the thigh below the inguinal ligament. It is purely sensory and supplies the upper portion of the thigh. Section of the nerve results in loss of cutaneous sensibility in this region. Neuralgia of the external cutaneous, meralgia paraesthetica, is not an uncommon condition. It is characterized by spontaneous pains and diminished sensation in the region supplied by the nerve

Genitocrural Nerve

The genitocrural nerve supplies sensory fibers to the middle of the upper part of the thigh and the scrotum. Division of the nerve results in no loss of sensation but may cause pains in the upper part of the thigh and the scrotum.

torius, and pectineus muscles, and gives branches to the psoas and the adductors Several sensory branches supply the antero-internal surface of the thigh The *internal saphenous nerve* continues on down,

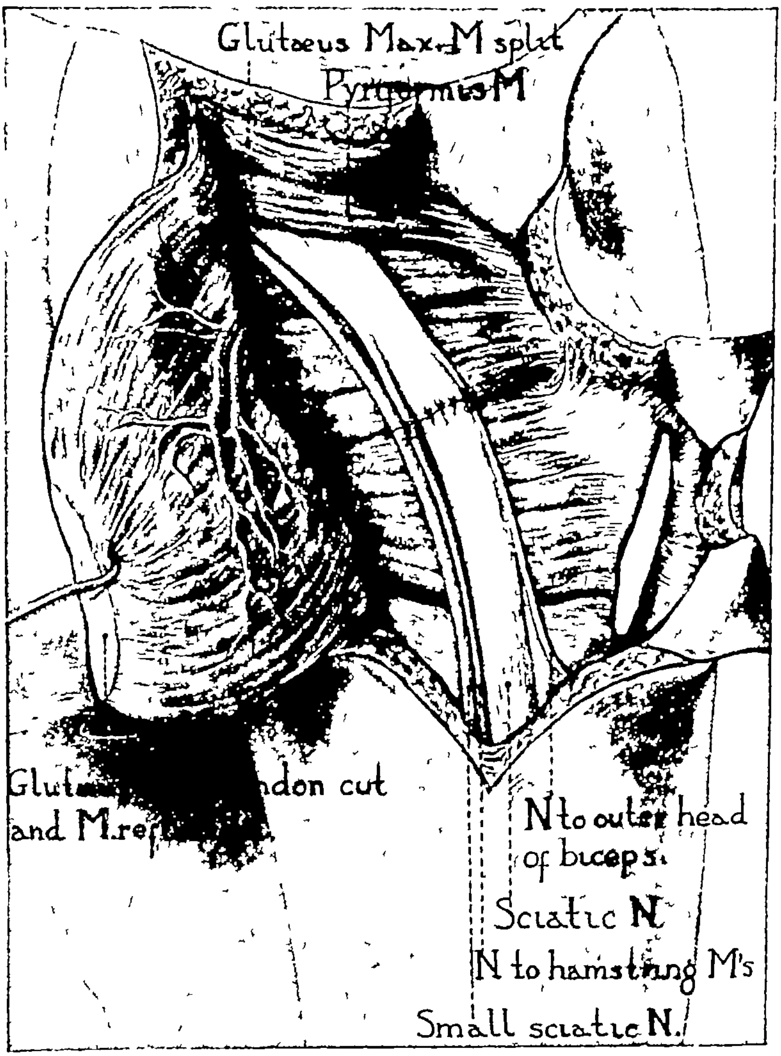


Fig 55—Exposure of the sciatic nerve with separate suture of the small sciatic, the nerve to the hamstrings, the sciatic, and the branch to the femoral head of the biceps The gluteus maximus muscle has been cut at its insertion and reflected medially, together with the large gluteal vessels (Stookey Surgical and Mechanical Treatment of Peripheral Nerves)

crosses the inner side of the knee, and descends on the inner aspect of the leg to the foot.

Effects of Injuries—Injury to the *anterior crural nerve* is comparatively rarely encountered with war wounds, possibly again because of its close proximity to the great vessels which, when damaged on

heal, the result is that *four to six months* frequently must elapse between the time of the injury and the time when the nerve can be repaired. Loss of soft tissue, broken bones, osteomyelitis, and foreign bodies, all further delay the time at which repair of the nerve can be safely undertaken.

Awaiting Spontaneous Recovery.—Spontaneous recovery of function of paralyzed muscles occurs in some cases wherein the nerve is not actually divided at the time of injury but merely bruised. It may therefore, be proper to withhold surgical exploration for a period of four to six months after the injury to allow spontaneous recovery to take place. Repeated careful clinical examination should, of course, be made from time to time to note any contraction of the field of sensory loss, return of muscle tone, or improvement in the reactions of the muscles to electrical stimulation. To await spontaneous regeneration longer than three months after a wound has healed is rarely considered justifiable, although it is generally recognized that the first clinical sign of regeneration may frequently not appear until much later

Exposure Followed by Conservative Treatment.—The time at which exploration should be undertaken in these cases has been a problem to all doing neurologic surgery Experience has indicated that a radical attitude for exposure of the nerve, with conservative treatment after exposure, is best in the majority of instances. If this practice is followed, then it will happen, of course, that some who might have recovered without surgical treatment will undergo a needless operation. But even among a certain number of these patients regeneration may be hastened rather than jeopardized by liberating the nerve from scar tissue and by preparing a more suitable bed for the nerve. On the other hand, if loss of substance of a nerve is found at operation, the nerve may be sutured and the time lost in waiting for spontaneous regeneration saved. Extensive regressive changes in muscles, joints, and tendons are thereby lessened and better end results are obtained. This is of special importance in association with lesions of the ulnar nerve, since the small muscles of the hand undergo very early and marked regressive changes which are particularly incapacitating. Too much emphasis, however cannot be laid on conservative treatment of the exposed nerve.

Second Exposure Followed by Suture.—If no signs of regeneration have occurred within six to eight weeks after a nerve has been liberated, exploration again, with suture, is indicated. Although it is true that in such cases some time has been lost, if regeneration should occur after liberation only complete return of function may take

Iliohypogastric and Ilio-inguinal Nerves

The iliohypogastric and ilio-inguinal nerves arise from the first lumbar root. They are sensory nerves but with no area of exclusive sensory supply. Injury to the nerves results in no loss of sensibility but may give rise to pains in the upper outer, and upper inner, portions of the thigh

Lumbosacral Plexus

While the lumbosacral plexus gives rise to all of the nerves of the lower extremity, injuries of the plexus are seldom encountered, owing to the associated serious and usually fatal injuries to great vessels and other tissues and organs which accompany them

However, in the differential diagnosis of lesions of nerves of the lower extremity, the segmental supply of the muscles of the lower extremity must be considered The surgeon had best refer to the complete tables of segmental supplies of peripheral nerves available in the standard works on anatomy

GENERAL PRINCIPLES OF NERVE REPAIR

Indications for Surgical Measures

Awaiting Subsidence of Infection—An injured peripheral nerve can be explored and, if necessary, sutured at any time within *five or six hours* of the injury, provided that thorough débridement and cleansing of the wound is done *

Under conditions of combat, however, most wounds are already infected when they are seen by the neurologic surgeon In such cases, the first consideration must be to treat the infection and secure sound healing Not until the wound has completely healed and has remained healed for about *three months,* should an attempt be made to suture a divided nerve † When this interval of safety is added to the time already required for the infection to subside and the wound to

* Since the advent of the sulfa drugs many operations can be performed at a later period than formerly was considered possible, especially if the wounded persons have taken the drug orally when injured or have had it sprinkled in the wound at the time of the original dressing Under these conditions many wounds can be explored a number of hours later and at a time which formerly would have been considered certain to spread infection.

† With use of sulfa drugs, early wound healing may be obtained and the delay formerly considered necessary for wound infection to subside before exploration could be undertaken may be greatly shortened Thus, exploration and repair may be attempted far earlier than heretofore has been considered possible Control of infection in the past has been one of the prime causes of delay It is obvious that the earlier the nerve can be safely repaired the better the end-result.

stances failure to obtain motor responses on stimulation of the nerve, either proximal or distal to the original suture, need not necessarily indicate failure of regeneration. This may merely mean that the regenerating neuraxes have not yet reached the motor end-plates in the muscles to which they are destined, although they may have successfully spanned the point of the suture and still may be actively growing.

Interpretation of Findings.—The point to be stressed, therefore, is that in attempting to appraise success of an earlier nerve suture by means of electric investigation, the findings obtained by this method of study must be interpreted not only in conjunction with the gross appearance of the nerve at the site of the suture but, also, by evaluation of clinical signs in relationship to the distance which the nerve must grow and the interval of time which has elapsed since the anastomosis was made. This shows the average rate of regeneration of the more important peripheral nerves.

Liberation of Nerve from External Scar

Dissection of the nerve from its bed of scar tissue is continued until the nerve has been completely liberated. This is occasionally spoken of as "external lysis." When the actual anatomic continuity of the nerve has not been broken but its physiologic conductivity has been interrupted by the constricting action of scar tissue about it, liberation of the nerve, without any other measure, may suffice to bring about return of function.

Lysis of Intraneural Scar Tissue

In some cases, after the nerve has been liberated from its bed of scar tissue, a fusiform swelling of the nerve will be found at the site of the original trauma, which is due to scar tissue within the nerve trunk. The effect of this scar tissue is to constrict the funiculi and to interfere with, or entirely to prevent passage of, nerve impulses. If this scar is not too dense, its constricting action on the funiculi occasionally may be overcome by "internal lysis" of the nerve. This consists of inserting into the fusiform swelling a fine hypodermic needle and injecting into the scar tissue, under pressure, 2 to 5 cc. of physiologic salt solution. If the scar is not too dense, the salt solution stretches it, thus relieving the constriction of the encircled funiculi.

Some surgeons make longitudinal incisions in the sheath of the nerve, but this practice appears seldom justified, since the scar tissue rarely involves the epineurium alone, but pervades the entire nerve trunk. Incisions into the nerve, deep enough to cut the scar, would

proximal or distal to it and, when possible, both proximal and distal A nerve which is exposed where anatomic relationships are normal can be more easily identified than elsewhere; and then the nerve can be followed into those regions where scar tissue has destroyed and distorted the normal anatomic characteristics

Electric Examination of Exposed Nerve

After the nerve has been exposed, examination of the injured nerve by stimulation with an electric current may be extremely valuable in determining whether or not the nerve has preserved its anatomic continuity within the scar tissue A simple galvanic current, obtained from an ordinary wire, will suffice for this purpose, or the surgeon may use faradic current, such as is obtained from a simple laboratory inductorium

Stimulation Proximal to Scar.—If stimulation of the nerve proximal to the scar tissue causes contraction of muscles normally innervated by that nerve distal to the scar, the fact of anatomic and physiologic continuity of the nerve is thereby established. In such a case it may be that any impairment of the physiologic function of the nerve observed preoperatively was due to constriction of the nerve either by scar surrounding it or by the action of scar tissue actually within the nerve trunk. In such instances the greatest importance attaches to the maintenance of anatomic continuity of the nerve while it is being dissected from scar tissue

If stimulation of the nerve proximal to the scar fails to elicit any true response from the muscles distal to it, which are normally supplied by the nerve, this does not necessarily indicate loss of anatomic continuity Compression of nerve bundles by scar tissue, either about the nerve trunk or within it, may be responsible for complete physiologic block without any gross anatomic interruption In such cases, if the pressure has not been too great, or present too long, return of physiologic conductivity may be expected following release of the nerve from scar tissue.

Erb's Paradoxical Response—Very rarely a response may be obtained by electric stimulation of an injured nerve distal to the site of injury, but no response elicited by stimulation above, or at, the point of injury This is known as "Erb's paradoxical response" and is found associated with slight pressure on the nerve Following correction of this condition a normal electric response should appear.

Absence of Response—Electric stimulation occasionally may be called for during reoperation at the site of an old nerve suture which has failed to produce clinical improvement. Under these circum-

Excision of all terminal scar tissue is mandatory if good functional results are to be obtained following suture. In doing this it is desirable that section of the nerve be carried out serially through the scar until the individual funiculi are seen standing out free of scar tissue from the cut end of the nerve. This must be done regardless of the resulting defect in the continuity of the nerve As a practical consideration, the intraneural scar should not actually be excised until the surgeon is ready to proceed immediately with the end to-end suture, since it is well to utilize this pathologic tissue for grasping and handling the nerve trunk during the various manipulations which are necessary before the nerve suture can be made. This is particularly true in those cases wherein the two-stage stretching operation may be needed.

Principle Applying to Treatment of Partially Divided Nerves

In these instances the injured nerve is made up of both intact funiculi and scar tissue, with a larger or smaller number of severed funiculi. Partial nerve suture, as a rule, cannot be done successfully without producing sharp angulation or "kinking" of the still undivided portion of the nerve. This angulation of the sound part of the nerve interferes with its conductivity and for this reason it is usually best to convert a partial transection into a complete transection, following this with careful end-to-end suture.

Exception to the general rule about converting partial into complete nerve sections before suturing will, of course, be made from time to time. For instance, in fresh wounds made with sharp instruments, there may be no loss of nerve substance and no scar to excise, so that approximation of the free ends can be accomplished by one or two sutures in the epineurium, with very little or no "kinking" of the rest of the nerve. Another exception to the general rule is in the case of partial division of the sciatic nerve. This nerve is actually composed of two distinct nerves, the tibial and peroneal, enclosed in a common sheath. Injury to the sciatic nerve may be confined entirely either to the peroneal or to the tibial nerve. In such cases, an attempt may properly be made to suture the divided portion of the nerve, peroneal or tibial, without dividing the intact component. When this is done, however the intact portion should be liberated from the severed portion over a great enough distance so that there will be no sharp angulation of the uninjured part of the nerve when the divided ends are approximated and sutured.

damage the funiculi and, in the process of healing, additional scar would form, probably greater than that from which the surgeon had sought to give relief

Excision of Intraneural Scar or Neuroma in Continuity

When the intraneural scar tissue at the site of trauma is large and is especially hard and dense, it is often referred to as a "neuroma in continuity" In such cases internal lysis of the nerve by the injection of salt solution will fail to release the nerve bundles sufficiently to allow them to conduct nervous impulses There is only one alternative, namely, complete excision of the fusiform swelling containing the scar tissue and approximation of the proximal and distal segments by means of end-to-end suture This may well appear to be a radical procedure But in these cases, wherein the intraneural scar is very dense, it is mandatory, for unless this be done, nervous impulses will be permanently blocked at this point.

When the swelling caused by scar tissue in the undivided nerve is *neither very soft nor very hard*, judgment is required in deciding whether to limit surgical intervention merely to liberation of the nerve, plus internal lysis of scar tissue, or whether radical excision of the scar tissue, followed by suture, is indicated No general criteria can be given here which will decide the issue for the individual case Here the experience and judgment of the individual surgeon is all important, In general, conservative handling of the exposed nerve is best. However, if the injury is of long standing, the disability great, and the intraneural scar tissue very dense, excision of the scar is probably indicated On the other hand, should the conservative course be chosen, then the patient must be closely observed following the operation and the surgeon prepared to revise his original opinion

Excision of Terminal Scar Tissue or Terminal Neuroma

If a nerve has been actually severed by the original trauma, exploration usually will disclose a hard, knoblike swelling at the end of the proximal segment of the nerve This swelling frequently is referred to as a "terminal neuroma" It is composed partly of scar tissue and partly of the curled ends of the regenerating neuraxes which have been frustrated in their efforts to grow peripherally but which, nevertheless, have continued to grow and to form whorls of neuraxes, commonly called "Perroncito spirals" A slight swelling of the proximal end of the distal segment of the nerve is frequently encountered This is smaller and usually softer and is composed only of scar tissue without the curled ends of neuraxes

Mobilization of Nerve

Simple mobilization of the nerve will overcome many of the lesser defects in its continuity By this is meant not only liberating the nerve from its bed of scar tissue but also freeing it from various restraints along its course for a considerable distance both above and below the region of the difficulty Normally there exists a great deal of slack in the nerve to allow for the various positions which the movement of skeleton and muscle impose on it. After thorough mobilization, traction at the end of the nerve will take up this slack, particularly if the arm has been placed in a favorable position.

Actual stretching of the nerve should contribute only a very minor fraction of its apparent lengthening. It is a well-established fact that excessive stretching may produce rupture of neuraxes within the nerve trunk and also degenerative changes in the anterior horn cells within the cord.

To mobilize the nerve it may be necessary to sacrifice some of its branches. It is of importance, therefore, to know which are the more important functions served by each of the large peripheral nerves so that these functions may be preserved. However to illustrate the principles involved, it might be pointed out that in repair of the ulnar nerve near the elbow the articular branches of the nerve, together with the branches supplying the flexor carpi ulnaris and the ulnar head of the flexor profundus, might reasonably be sacrificed if this were necessary to secure suture free from tension and to insure regeneration of that portion of the nerve which supplies the all-important intrinsic muscles of the hand. In repairing an injury to the median nerve, it is more important to insure good return of sensation to the palmar surfaces of the first three digits of the hand than to preserve each of the muscular branches of the nerve which supply the volar muscles of the forearm. Similar considerations apply to all of the larger peripheral nerves.

Relaxation of Nerve through Flexion of Joints

Flexion of a joint often will shorten the course of a nerve which passes in front of it. This principle is often utilized to release tension on a nerve and to help close the gap between nerve segments; it is one of the most frequently used and most valuable procedures employed in repair of nerves after injury

Flexion must, of course be maintained while the end-to-end suture is performed. The failure of an assistant to hold the arm in the correct position, or sudden extension of the arm by the patient, would rip out the suture line. The chief reason for general anesthesia being

Axial Alinement

Precise realinement of the two ends of a divided nerve, with accurate apposition of the divided nerve bundles, is unquestionably desirable Occasionally, under favorable conditions, this can be realized, especially when a large nerve has been cleanly divided by a sharp instrument, when there has been no loss of nerve substance and when suture can be done at once However, these conditions rarely obtain in war

Whenever the ends of a severed nerve are cut back from the point of division in order to remove scar tissue, it is found that the size, the position, and the general pattern of the various bundles which make up the nerve vary so greatly that usually it is not possible to identify the bundle groups appearing in the distal cross-section with those seen in the proximal cross-section

For anatomic and theoretic reasons, therefore, as well as for practical, technical reasons, precise funicular approximation almost never is obtained in the repair of divided nerves, especially of those nerves injured under conditions of war Effort should be made, however, to maintain the general axial alinement of the two nerve segments with as little rotation as possible Occasionally, some peculiar anatomic feature, common to both segments of the nerve, will serve as a guide In cases wherein the continuity of the nerve has not been completely interrupted by the original accident, it will be found helpful to place small "identification sutures" of black silk through the epineurium over corresponding funiculi of the nerve trunk proximal and distal to the part to be excised before the scar tissue is excised

METHODS OF REPAIR WHICH CAN BE USED

Since actual loss of nerve tissue results in association with most injuries to peripheral nerves, various procedures frequently must be utilized to overcome these defects Some of these measures facilitate approximation of nerve segments through release of tension These include (1) mobilization of the nerve, (2) relaxation of the nerve through flexion of neighboring joints, (3) relaxation through transposition of the nerve to a shorter course, and (4) gradual stretching of the nerve by means of a two-stage operation

Other recommended methods of nerve repair include (1) nerve crossing, (2) nerve grafting, (3) the fibrin method of repair, and (4) direct implantation

nerve, that is, two or three weeks, depending on the tension under which preliminary suture of the nerves was effected, the extremity is gradually brought into extension and, as this takes place, the nerve is automatically stretched. This, however, must be done in slow stages over a period of two or three weeks so as to avoid damage to the nerve and injury to anterior horn cells. After the nerve has been sufficiently stretched, the second stage of the operation is performed. At this operation the scar tissue holding the traction sutures is excised from the nerve until funiculi of normal appearance are seen. The extremity is again flexed and end-to-end suture performed.

Nerve Crossing

Nerve crossing is a rational method for repairing defects in the continuity of injured nerves but it is applicable in only a very limited group of cases. In this procedure a healthy nerve is cut across and the end of the proximal segment is sutured to the distal segment of the injured nerve. The best known example of this method of repair is the hypoglossal facial nerve crossing, when the proximal segment of the hypoglossal nerve is sutured to the distal segment of the facial nerve.

Nerve crossing has very limited application for two reasons. In the first place, it requires sacrifice of a healthy nerve for repair of an already injured one. In the second place, it is necessary that the two nerves lie in close proximity to each other This procedure is occasionally applicable in repairing defects of the median nerve in the forearm. Here, the radial nerve, after it has given off its branches to the flexor muscles, is entirely a sensory nerve and can be sacrificed to repair the median nerve on the ground that recovery of sensation on the palmar surfaces of the hand and first three digits is more valuable than the preservation of sensation on the dorsum of the hand and fingers.

Nerve Grafts

Experimentally nerve grafting with either single or multiple (cable) transplants has attracted considerable interest and much has been promised by this procedure. Clinically however the end-results in those cases in which nerve grafting has been tried have been very disappointing (Fig. 56) Nerve-transplant operations for the repair of peripheral nerves performed after the last war in the United States Army hospitals under ideal conditions by trained neurosurgeons were used approximately sixty times. Of these sixty instances, according to Frazier in only a few cases could the result be considered successful he concluded that the use of transplants

employed in suture of nerves is to prevent such a complication from occurring.

By suitable methods, the extremity should be immobilized in flexion after the operation, until the epineurium has grown firmly together between the two segments of the nerve and until after the downgrowing neuraxes have passed this line of suture and entered the distal segment. In most cases, four weeks of immobilization will be long enough, but if the suture was made under considerable tension, six or eight weeks will be better.

Transposition of Nerve

The course of certain nerves can be shortened and tension on them relaxed by transposing them from their natural positions to new positions For example, transposition of the ulnar nerve from behind the internal condyle to a new position in front of it greatly shortens the course of the nerve, allows it to relax, and allows approximation of its severed ends which, otherwise, would be impossible Even after transposition of the nerve, flexion of the elbow is still effective in obtaining further relaxation and always should be employed in conjunction with transposition Satisfactory transposition of a nerve without division of some branches is rarely, if ever, possible and an attempt to transpose without division of branches may seriously reduce the degree of relaxation obtained by the transposition

Two-Stage Operation for Stretching Nerve

The two-stage method of nerve suture has proved to be very effective and it is recommended when (after mobilization, flexion, and transposition of the nerve) approximation of the ends cannot be obtained except under greatest tension In the first stage strong silk sutures are passed through the scar tissue at the two ends of the divided nerve trunk. These are placed, if possible, in such a position as to bring about, when they are tied, an overlapping of the two nerve ends equal to the combined length of the sacrificed tissue which will have to be excised from the ends of the two segments of nerve before their ends can be sutured Sutures thus placed in scar tissue will carry far more tension without pulling out and with far less damage to nerve fibers than would sutures similarly placed in normal nerve tissue After the nerve ends have been drawn together and the traction sutures tied, the wound is closed and the extremity is immobilized in a cast in a position of maximal relaxation for the sutured nerve After sufficient time has elapsed for fibrous union to have occurred between the two sutured segments of the

to be no reason why this procedure might not be applied to larger nerves, its use clinically is definitely limited to cases in which the nerve ends can be brought together without undue strain.

If applied to the repair of smaller nerves, such as the facial, and used in connection with cable transplants where there is little or no tension on the suture, this method may prove of great value.

Direct Implantation of Nerves

Neurotization of denervated muscle can be obtained in occasional favorable circumstances by direct implantation of a motor nerve into the muscle. The neuraxes from the cut end of the implanted nerve will grow into the muscle and form motor end-plates. After six weeks to three months, prompt responses will be obtained on electric stimulation and the muscle will regain its former volume, color, and contour. Practically it can seldom be applied, since only rarely can a motor nerve be devoted to the exclusive supply of a given muscle. However it may be found of value for implantation of motor branches.

SELECTION OF PROCEDURE

After the nerve has been liberated from its bed of scar tissue any defect in continuity resulting from loss of tissue at the time of the original injury will be apparent. In addition, it will be possible to estimate the probable extent of neural scar which will have to be excised from the nerve trunk or the ends of the nerve segments before end-to-end suture can properly be performed.

At this point in the repair before any of the neural scar has been excised, the surgeon must select the procedure by which he intends to overcome the defects in continuity of the nerve trunk. The relaxation obtained by mobilization of the nerve, both proximal and distal to the injury must be tried, the release of tension obtained through flexion of neighboring joints must be tested, the feasibility, and need, for transposition of the nerve must be carefully weighed. During these manipulations, so far as possible, the scar tissue involving the nerve should be used for application of traction in general handling, rather than the delicate ends of nerve from which scar tissue has been removed preparatory to suture.

If the defect in the nerve will be so great as to indicate that approximation of the severed ends will be possible only under greatest tension, even after extensive liberation, flexion, and transplantation of the nerve have been carried out, then the two-stage nerve-stretch-

to bridge defects was a dismal failure and that the results of nerve stretching in a two-stage operation, even with the nerve under great tension, gave better results.

In civil practice, one is seldom confronted with the necessity for nerve grafting, consequently, few grafts have been attempted A few

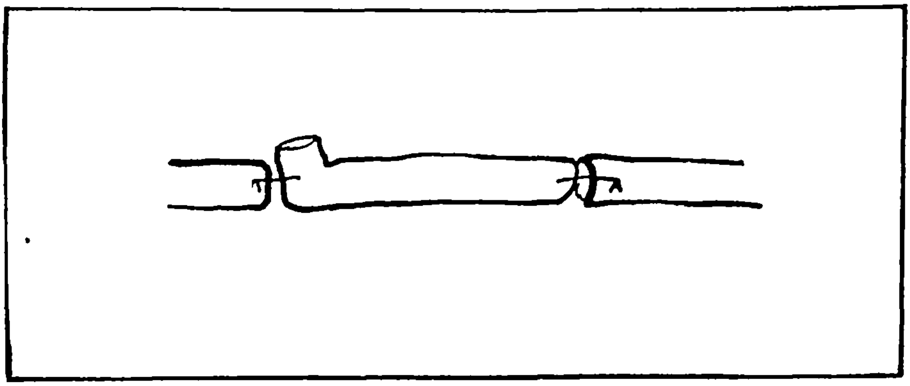


Fig 56—Why downgrowths may not take place in a graft Such apposition as is shown here may occur if the sutures are not properly placed or properly tied End-to-end apposition must be obtained

cases are known, however, in which single or cable grafts have been used successfully The interposition of free graft between the cut ends of the facial nerve has brought about excellent regeneration and motor function in the facial muscles, so that the principle of the nerve graft must still remain as a sound one

Fibrin Method of Nerve Repair

A new and original method of nerve repair, so-called *fibrin suture*, has recently been described by Young and Medawar The method consists simply in holding the cut stumps together and pouring around them plasma which has just been mixed with a little strong tissue extract.* In about a half minute to two minutes, according to the age of the plasma and the strength of the extract, the plasma clots to a firm jelly, which sticks to the nerves and holds the stumps together The plasma is freely permeable and, during the subsequent days, is dissolved away, although remaining long enough to allow firm union to be established between the divided ends

This is an extremely ingenious and technically simple method for nerve repair and apparently has given excellent results when used in work with the smaller laboratory animals Although there appears

* For details of preparation of the fibrin suture material see The Lancet, 2 123 (Aug 3), 1940

bundles. When scar is present, the whole cut end is a uniform, bleeding surface. By gently squeezing the nerve trunk with the fingers, the bleeding can be controlled and the cross-ends thoroughly inspected. An ordinary library magnifying glass, which can be sterilized, is helpful.

The incisions in the nerve should be made sharply, with a thin blade such as is used in knives with removable blades. As the incision is made, traction should be maintained from three equidistant points on the circumference of the nerve so that the incision is carried through all tissues at a right angle and in the same plane. The successive incisions are not carried completely through the nerve until the surgeon is satisfied with the nerve ends, when two sutures are passed, one on each side of the nerve. In this manner axial rotation is minimized and continuity of the nerve trunk is maintained, making suture less difficult. Naturally, if anatomic interruption has occurred, each end is dealt with separately

Sutures

When possible, anatomic continuity of the nerve trunk is maintained until after two 000 catgut stay sutures have been passed, one on each side of the nerve at equidistant points. When anatomic continuity has been lost, the sutures are placed so as to bring the nerve ends together with the least possible axial rotation. These sutures are carried somewhat deeper than the epineurium and should be placed opposite each other The suture is tied with forceps and the ends are left long. Clamps are placed on the ends and these are then used to steady the nerve while the remaining sutures are placed. When the first two sutures are placed exactly opposite each other, the remaining sutures are more readily made and more even approximation is obtained (Fig. 57) Silk epineural sutures are then passed on the upper surface of the nerve, a sufficient number being used to bring the epineurium together and to close in all funiculi. The sutures are so placed as to include only epineurium and are tied with forceps, so that the edges of the epineurium are everted and accurate approximation is obtained.

After the upper surface has been sutured, the ends of one of the catgut stay sutures are passed beneath the nerve and the ends of the other over the nerve, thus bringing the undersurface of the nerve into view for the remaining silk epineural sutures. After these have been placed, the ends of the catgut stay sutures are cut and the nerve returns to its normal position. During suture the nerve ends

ing operation may be necessary In that case, the scar tissue at the ends of the two segments of the nerve must not be excised at this operation, since it is essential for holding the traction sutures of the first stage Scar, therefore, never should be excised either from the nerve trunk or from the ends of two segments of a nerve until all the problems incident to approximation of the nerve ends and their suture have been thoroughly considered and decisions have been reached covering all steps in the general program of repair

PREPARATION OF NERVE BED

The tissue bed must be prepared for the freshly sutured nerve The hemostasis must be meticulous, any ragged bits of scar tissue should be excised, and the old cicatricial bed should be smoothed out. Infolding of the scar is often better than excising it. Frequently, it is possible to swing a fascial slip over the old scar tissue bed, suturing it in place Such a fascial slip, however, never should be wrapped around the sutured nerve Free transplants of fat to the scar tissue bed are also to be avoided since this tissue seems to incite additional scar tissue reaction

TECHNIC OF END-TO-END SUTURE

Incisions

After the nerve has been exposed and freed from the surrounding scar, palpation of the nerve throughout the portion exposed is carried out to determine the consistency of intraneural scar and the level at which incisions in the nerve shall be made Intraneural scar can be recognized by palpation It may be present throughout a large part of the nerve trunk, in both the central and distal ends, and is probably the most common cause of failure in nerve suture, hence, the importance of making the incision, if possible, beyond the region of scarring

When the level of the suture has been determined, the approximate gap to be bridged is estimated by gentle traction on the scar tissue of the nerve trunk and the nerve is gently stretched. This should be done before excision of the scar, so that the scar can be used to make traction Partial transverse incisions through the scar are then made, with inspection of each cross-section after incision, and the making of these incisions is continued until ends free of scar are obtained. Normal ends are readily recognized by discrete nerve bundles, with connective tissue of normal appearance between them When free of scar the cut ends usually bleed freely between the

with sufficient allowance for retraction to permit union without tension on the line of suture (Fig. 58)

Care must be taken to make sure that *no kinks or angles* will result following the suture such as may occur when the nerve is hooked around a muscle, and due allowance must be made for the normal contractions of muscles and for movements of the parts.

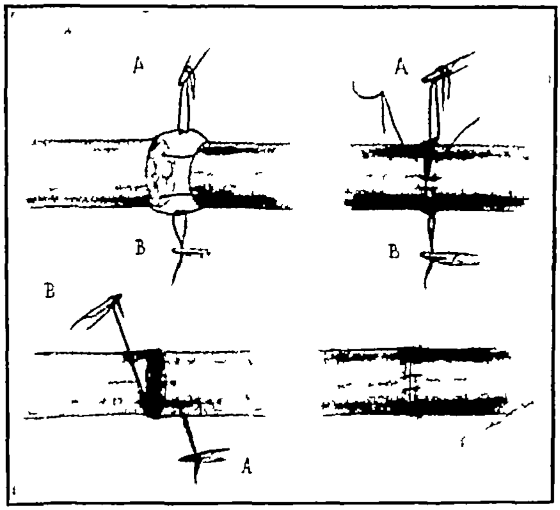
In *partial nerve crossing* (Fig. 59) the level and the thickness of the partial nerve segment which is to be raised having been de-

Fig. 58.—Complete nerve crossing. The distal end of one nerve is brought into end-to-end apposition with the central end of another nerve. End to-end suture is done (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

termined, two fine silk sutures are placed at this point. A thin, narrow sharp knife is then inserted into the nerve at the point to obtain exactly the required thickness and the incision is carried upward the desired length. So far as possible, the longitudinal part of the incision is made between funiculi, which in some instances can be recognized by rolling the nerve between the fingers. In *order to* avoid possible injury to the remaining nerve trunk, the tranverse incision which frees the flap is made from within outward.

are constantly irrigated with warm saline solution, so that the least possible layer of blood is left between the nerve ends This constant irrigation also increases the visibility and permits more accurate work. The ends of the nerve should be brought together without undue tension if this is possible The sutures should not

I II.



III IV

Fig 57—Technic of end-to-end suture I, The nerve ends have been prepared for suture and two catgut 000 sutures have been passed slightly deeper than the epineurium at equidistant points on the nerve The sutures are tied and the ends clamped, serving to steady the nerve for passage of the fine epidural silk sutures II, Epineural silk sutures are being placed The sutures include the epineurium only A sufficient number is used to insure the approximation of the epineurium III, The catgut sutures are reversed, A being passed under the nerve and B over the nerve to bring the undersurface of the nerve into view and permit the epineural suture to be placed on the undersurface, as in II. IV, Nerve ends approximated and all sutures cut (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

deliberately be made so that a free space is left between the nerve ends The greater the distance between the nerve ends the more scar tissue between them and, consequently, the greater the resistance to downgrowing neuraxes

TECHNIC OF NERVE CROSSING

The technic of complete nerve crossing requires no special description other than that given for end-to-end suture The distal nerve is brought up to the central nerve trunk to which it is to be united, to determine the exact point at which the nerve should be severed,

each graft separately so as to establish the central and distal con nections with precision.

When the nerve to be grafted has been freed from the scar tissue and the nerve ends have been successively incised until a satisfac tory cross-area has been obtained, one or two stay sutures are passed at the proper level, before continuity of the nerve has been com pletely severed, so as to hold the nerve in alinement, prevent rotation, and help in fixation of the ends during suture. These stay sutures need not be tied, but each end can be clamped near its exit from the nerve. The distance to be bridged is then accurately meas ured with a centimeter divider

Source of Grafts

A skin nerve, such as the radialis or the external saphenous on the dorsum of the leg, can be used for grafts. In order to save time, another operating team may lay bare the skin nerve. Degenerated nerves such as are found in the leg on the side of an injury to the sciatic nerve, preferably should not be used. The sheath cells in such a nerve are no longer in active proliferation and there may be some increase in connective tissue, particularly if the injury to the parent nerve is of some standing.

Suturing

The skin nerve having been laid bare over the desired length, fine, waxed silk sutures on fine, curved or straight, smooth needles are passed at an interval equal to the distance to be bridged, as pre-

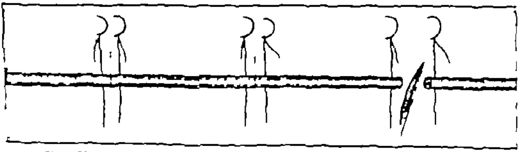


Fig. 60—Technic of nerve transplantation. A cutaneous nerve to be used for the free transplants has been exposed, the length of the grafts determined, and the sutures for each segment passed. The nerve is then cut into segments by a sharp, thin knife (scissors crush the nerve ends and should not be used) (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

viously measured (Fig. 60) A small margin is allowed for cutting the nerve segments. The sutures are all passed in one direction, the nerve being held tense by small forceps, either central or distal

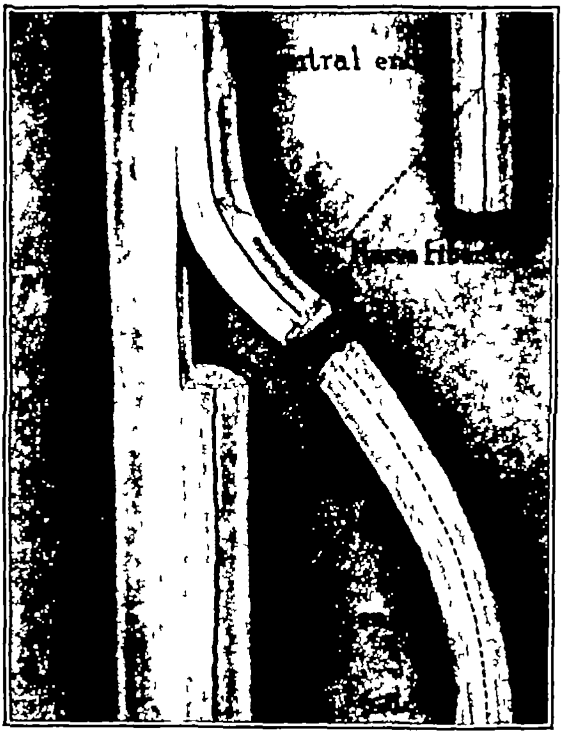


Fig 59 —Partial nerve crossing The distal end of one nerve is brought into apposition with a flap raised from the central end A small flap is raised to insure accurate end-to-end suture of the cut funiculi (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

TECHNIC OF NERVE GRAFTING

General Principles

This is so exacting a procedure that unless it be done by those having considerable practice, the results may be disappointing The utmost regard for minute points of technic is essential Success depends in great measure on the accuracy with which the grafts are brought end on end in precise contact with the cross-area of both the central and distal stumps While neuraxes may grow into the graft, the probability of such penetration is greatly diminished by faulty approximation For these reasons, in estimating the ultimate value of the graft, individual technic must be considered, for it plays a predominant role

A sufficient number of grafts should be taken to cover the cross-area of the central and distal stumps Unless this is done, many central neuraxes, having no path down which to grow, may become lost The aim of the surgeon should be to connect each funiculus, or group of funiculi, with a graft This can be accomplished by suturing

During the process of suture the nerve is irrigated with warm salt solution, thus creating a clear field and aiding in accurate funic-

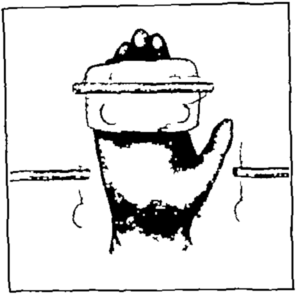


Fig. 62.—Technic of nerve transplantation. Nerve graft and sutures held in place on cotton pad ready to be transferred to operative field where nerve defect is to be bridged (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

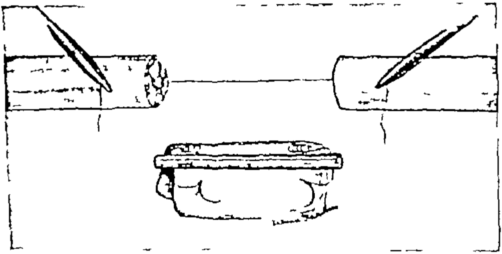


Fig. 63.—Technic of nerve transplantation. Nerve graft brought into operative field, cotton pad folded back, and nerve graft ready to be placed into defect in nerve. The nerve ends are held in place and steadied by a temporary through-and-through suture held by two forceps. The ends of this suture are not tied together in order to leave the operative field unobstructed (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

ular approximation of the graft. In this manner each transplant is sutured separately both distally and centrally with whichever

to the grafts Under no circumstances should the nerve segments to be used in the graft be held by forceps The sutures are then curled carefully so as to prevent entanglement, the needles all on one side and the free ends on the other

Cotton Pad for Lifting Nerve Segments

The nerve segments are cut with a sharp, thin knife and crushing of the nerve ends is avoided Each segment is then picked up by covering it with a smooth, moist cotton pad If the cotton is carefully placed over the nerve and sutures, they adhere to the moist cotton and each segment thus can be lifted from the wound and

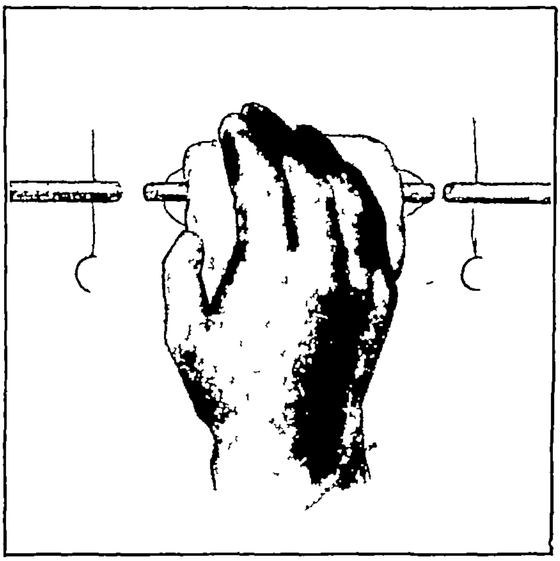
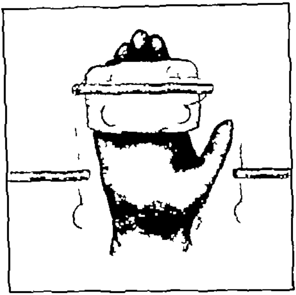


Fig 61 —Technic of nerve transplantation The sutures are carefully placed so as not to become twisted, and a moist cotton pad is laid over the nerve segment and sutures By gentle pressure, the graft and sutures are made adherent to the cotton pad and then all can be picked up without danger of pulling out the sutures, and the graft can be easily handled without trauma (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

placed in the operative field without handling By folding the cotton pad so that its free border is parallel to the transplant, the latter can be placed between the nerve ends so as to be in exact position for suture (Figs 61 to 65 inclusive) With the use of the cotton pad, neither the nerve nor the sutures are handled, the latter do not become entangled, the danger of pulling out the sutures is eliminated, and the nerve can be maneuvered into its proper position for suture with the least trauma A small stream of salt solution will be helpful in flooding the nerve off the cotton

During the process of suture the nerve is irrigated with warm salt solution, thus creating a clear field and aiding in accurate funic



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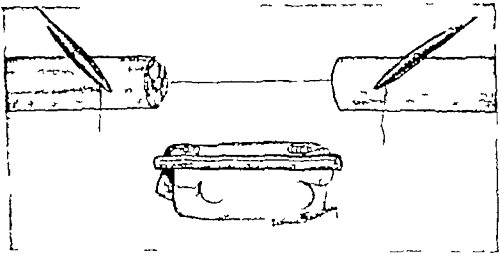

Fig. 63.—Technic of nerve transplantation. Nerve graft brought into operative field, cotton pad folded back, and nerve graft ready to be placed into defect in nerve. The nerve ends are held in place and steadied by a temporary through-and-through suture held by two forceps. The ends of this suture are not tied together in order to leave the operative field unobstructed (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

ular approximation of the graft. In this manner each transplant is sutured separately both *distally and centrally* with whichever

funiculus is desired The sutures must be tied with forceps and cut short

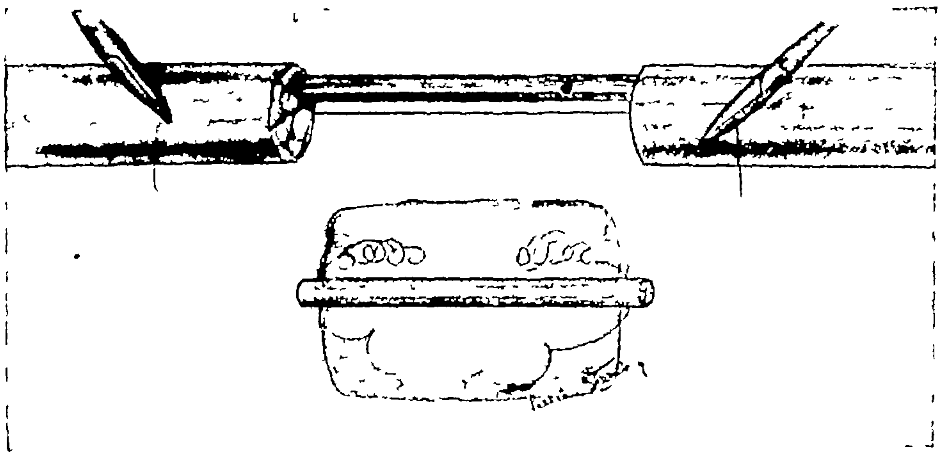

Fig 64—Technic of nerve transplantation (cable graft) One nerve graft sutured in place Great care and considerable skill are necessary to insure en-to-end approximation A second transplant is brought into the field and is made ready for suture (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

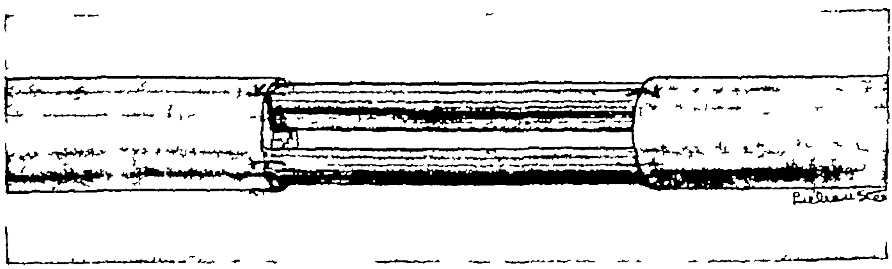

Fig 65—Technic of nerve transplantation Four nerve segments have been sutured in place, with space for two additional segments to complete the suture As much of the cross-area of the injured nerve as possible should be covered with nerve segments, provided accurate end-to-end approximation can be obtained (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

The accuracy of the graft depends in a measure on the correct placing of the sutures, the exact amount of tension in tying, and delicate manipulation by means of the sutures during the process of tying

TECHNIC OF NERVE IMPLANTATION

No special technic is required for direct nerve implantation The muscle fibers are split by blunt dissection and the branch of the nerve is then implanted into the muscle If the branch is fine, no attempt is made to pass a suture into the motor branch to fix it

to the muscular sheath. If, on the other hand, the nerve is fairly large, then a point of fixation through the epineurium to the muscle sheath is made (Figs. 66 67)

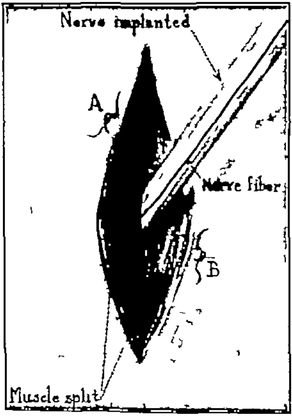

Fig. 66.—Direct nerve implantation. Muscle is split in direction of fibers and nerve brought into muscle and held by two lateral sutures, A and B. These are passed 2 to 3 mm. central to the cut end and serve to hold the nerve end in place (Stookey in Nelson's Loose-Leaf Surgery Vol. 2. Thomas Nelson and Sons)

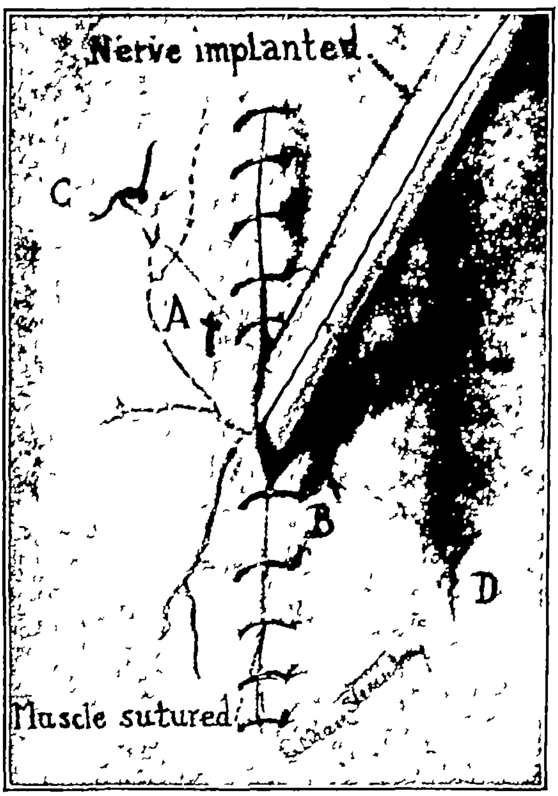

Fig 67—Muscle closed after implanting nerve The additional sutures C and D are passed through the nerve and muscle to prevent angulation of the nerve (Stookey in Nelson's Loose-Leaf Surgery, Vol 2 Thomas Nelson and Sons)

METHODS OF REPAIR TO BE AVOIDED

Both experimental and clinical experience warrant abandonment of certain methods of repair as of no value or as offering such slight opportunity for successful regeneration that they should be discarded. These methods are (1) suture à distance that is, bridging of nerve defects by a catgut cable (2) nerve flaps (3) nerve implantation and (4) tubulization.

SPECIAL CONDITIONS

Injuries of Facial Nerve

Injuries to the cranial nerves were not uncommon in the war of 1914–1918. Foerster reported 423 instances of involvement of cranial nerves out of a total of 3907 injuries of nerves. These injuries of cranial nerves were distributed as follows

Trigeminal	215
Facial	120
Glossopharyngeal	7
Vagus	21
Spinal accessory	30
Hypoglossal	30

Of these, only injuries to the facial nerve can be considered as surgical problems in time of war

Types of Injury.—Injuries of the facial nerve can be placed in three categories, depending on the site of the injury (1) injuries to the intracranial portion of the nerve, resulting from fracture of the skull, or from hemorrhage or infection within the facial canal (2) injuries occurring to the main trunk of the nerve after its emergence from the stylomastoid foramen and before its division into smaller branches, which normally takes place about 2 cm. anterior to the external auditory meatus; and (3) injuries to the smaller branches of the nerve in the face.

These groups require different methods of treatment. The first group is best treated by unroofing the facial canal, excising scar tissue, and bridging the defect in the nerve with a graft. In the last named group, the divided branches are so numerous and so small that suture is impossible. Most of the injuries fall into the second group and can be treated in several ways, depending in large part on the exact point at which the nerve has been severed.

Nerve-Crossing Operation.—When the main trunk of the facial nerve is divided in the neck just as it emerges from the stylomastoid foramen or immediately thereafter it is technically impossible

to utilize the central end of the nerve for any form of nerve repair Under such circumstances, the only method available is to perform a nerve-crossing operation, suturing the cut end of the distal segment of the facial nerve to the central segment of some other nearby motor nerve, almost always the spinal accessory or the hypoglossal

When nerve crossing is done, return of volitional control of the muscles of the face occurs, with the exception of the frontalis By facial crossing, the tone of the facial muscles is restored and, when the muscles are at rest much of the facial deformity is lost The ability to move the angle of the mouth, to wrinkle the nose, and to close the eye is restored, and a good cosmetic result is obtained.

After nerve crossing, however, associated movements are common, whether the crossing be with the hypoglossal or with the spinal accessory nerve If the hypoglossal is used, movements of the tongue may cause associated movements of the face If the spinal accessory is used, movements of the arm may induce associated movements of the face

Free Nerve Transplant—Wherever possible, however, interposition of a free nerve transplant between the divided ends of the facial nerve should be performed, for it is preferable to any form of nerve crossing, however successful the latter may seem After nerve crossing, irrespective of the nerve used, spontaneous emotional movements of the face are not recovered, whereas, when the neuraxes from the central segment of the facial nerve grow through the nerve transplants to reach the distal segment of the same nerve, excellent volitional and emotional responses are obtained

Nerve Irritation—Causalgia—Its Treatment

Many mild forms of nerve irritation, such as those due to compression by bands of scar tissue, to callus, or to foreign bodies, and the more severe forms, such as causalgia, can be relieved by appropriate surgical measures Surgical relief is more important in the presence of irritative nerve lesions than in the presence of the nonirritative forms, since irritative lesions cause severe and widespread trophic disturbances, such as scleroderma, ulcers, fibrosis of the muscles, contractures, and periarticular changes, which are more disabling than simple section of the nerve and total loss of conduction

In 1864 Weir Mitchell, Morehouse, and Keen described on the basis of the occurrence among the wounded of the Civil War in the United States of America, a most intense form of nerve irritation or neuritis to which they gave the name "causalgia" To their vivid description nothing has been added, although many cases were en-

countered in the course of the war of 1914–1918. The disease is also to be found in association with injuries of nerves occurring in civil life.

Symptoms.—The pains are severe and are brought on by the slightest touch. The patients remain by themselves, walk with great caution, and sit down very slowly as if trying to avoid the slightest shock or contact. They carry a painful hand in a guarded position, either within the blouse or protected by the other hand. If the lower extremity is involved, they usually remain in bed and resent any approach or any touching of the bed. Moisture seems to relieve the pain. An injured hand is often wrapped in a damp cloth, covered with a large amount of cotton, or even a rubber glove, to maintain the moisture If the foot is affected, it is wrapped in a wet cloth, or water is even poured into the boot. The pain is spontaneous, although it is accentuated and often is evoked by emotion. To one patient who was under observation the thought of New York Harbor with the tall buildings about it, caused exquisite pain, although New York was his home and he longed to return there. To another the view from the hospital window over a steep hill caused excruciating pain. To still another pain was caused by the sight of a patient on crutches walking over a highly polished floor and by the fear that he might fall. Because of the violent exacerbation of pain brought about by emotion or other sensation, many patients prefer to be alone away from all stimuli which tend to increase their suffering.

The pain is usually limited to the superficial structures. Slight contacts are more painful than heavy pressure. The skin usually is dry glossy and warm the fingers usually are thin and tapering. In some cases it is found that the skin is moist and sweating is profuse

Involvement of Sympathetic Fibers.—The nerves most frequently involved are those which contain a large number of sympathetic fibers, such as the median in the upper extremity and the tibial in the lower extremity The pain is usually referred to the area of peripheral distribution, but many times the painful area is larger than that usually attributed to distribution of the nerve in question. This fact, coupled with the obvious vasomotor disturbances and the influence of emotion, has led to the view that the sympathetic fibers are essentially responsible for the pain.

Mild Causalgia.—A milder form of causalgia, not traumatic in origin, which involves the face, hands, or legs, has been described by Tinel (1921) and termed by him neuralgia of the sympathetic

to utilize the central end of the nerve for any form of nerve repair Under such circumstances, the only method available is to perform a nerve-crossing operation, suturing the cut end of the distal segment of the facial nerve to the central segment of some other nearby motor nerve, almost always the spinal accessory or the hypoglossal

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scar and careful reconstruction of the field should be made, since injection may be vitiated if thorough neurolysis has not been done.

PERIARTERIAL SYMPATHECTOMY.—Since the important role of the sympathetic structures in various forms of neuritis has been recognized, measures directed toward the sympathetic system have been evolved in the treatment of certain of these painful combinations. Of these, one of the most important is periarterial sympathectomy

Since sympathetic fibers to the walls of the vessels are received at various levels, it is not to be expected, for example, that decortication of the brachial artery in the arm would destroy the sympathetic nerves to the vessels of the hands, as these receive a rich sympathetic supply from the median nerve in the forearm and at the wrist. Possibly this is one of the reasons why so many failures are reported after such an operation and why the relief is only temporary: only part of the nerve supply is removed over a relatively short segment of the artery too far from the region of the pain and sufficiently high to allow a new increment of sympathetic fibers to reach the vessels at lower levels.

EXCISION OF PORTION OF SYMPATHETIC TRUNK.—If relief of causalgia cannot be obtained by periarterial sympathectomy excision of the appropriate portion of the sympathetic trunk should be undertaken.

Amputation Neuroma

These enlargements on the central end of a divided nerve are formed by regenerating neurons and sheath cells. Connective tissue closes off the cut end and prevents downgrowth of the regenerating fibers. The blocked neuraxes are seen to pass in all directions in their effort to reach the distal end, some are turned on themselves and form spirals and twisted regenerating neuraxes, usually about a single neuraxis—the so-called Perroncito spirals. The endoneural and perineural connective tissue is apparently stimulated by regenerating neuraxes, thus setting up more or less of a vicious circle, the connective tissue preventing downgrowth of the fibers and the fibers stimulating growth of the connective tissue. Huber and Lewis (1920) found that if regeneration of the neuraxes could be prevented until connective tissue had closed over the nerve trunk, neuromas did not form. They emphasized that absolute alcohol injected into the nerve trunk somewhat above the level where the nerve was sectioned delayed regeneration of the neuraxes and prevented the formation of neuromas. They considered that "absolute alcohol injected into the nerve some distance above the plane of suture is

nervous system The sensations are not those of actual pain but of burning and throbbing, with vasomotor disturbances

Pathology.—The pathologic characteristics of some forms of neuritis are little understood In many cases of painful conditions of the nerves, definite morphologic changes have been found In consequence, the methods used to treat the various forms can be considered for the most part empiric. Especially is this so in relation to the treatment of causalgia and in the use of ramisection and perivascular sympathectomy.

Treatment—The surgical measures used for the milder forms of nerve irritation are more direct in their approach and are more definitely established These forms of nerve irritation, such as those due to simple compression, are relieved by freeing the nerve from surrounding scar tissue and either transplanting the nerve or, when possible, making a bed free of scar At times the lesion is both extraneural and intraneural

INJECTION OF ALCOHOL—Injection of 60 per cent alcohol into the nerve trunk above the level of the injury will relieve the pain in some forms of mild, as well as in some forms of severe, neuritis In other cases, especially if dorsal ganglia are involved, peripheral injection of alcohol is of no avail

It is said that 60 per cent alcohol does not bring about motor paralysis but produces degeneration of the sensory fibers alone Unfortunately, this does not always hold true, and it is not unusual to see patients with total sciatic paralysis who have been treated for "sciatic neuritis" by injections of 60 per cent alcohol In some instances the paralysis has lasted for more than two years In treatment of a nerve of which the function is so dominantly motor, injections of alcohol are to be used with caution, if paralysis of the motor fibers is to be avoided However, in cases of severe neuritis with marked secondary changes in the structures supplied by the nerve, total paralysis of the nerve is to be preferred to an incomplete irritative lesion, since the secondary changes are more disabling than paralysis

Alcoholization of nerve trunks in cases of neuritis has been in use since the original work of Schlosser and has earned an important position in the surgical relief of irritative lesions of the nerve. Two to 3 cc of 60 per cent alcohol should be injected into the nerve trunk through a fine needle entered above the level of the lesion and at different points of the circumference of the nerve, so that the alcohol can penetrate to all the funiculi and can be evenly distributed In addition, the nerve should be freed from all surrounding

Atrophy—Atrophy from disuse does not differ from the wasting seen in any prolonged period of inactivity There is, in addition, an atrophy due directly to nutritive changes from loss of innervation. This affects muscle, bone, and skin, and is apparent in the glossy and often cyanotic appearance of the latter

Deformity—Deformity occurs first as a result of flaccidity of groups of paralyzed muscles and thus can be corrected passively The habitual position is that produced by gravity and contraction of the unparalyzed groups of muscles. If this condition is allowed to continue without treatment, contractures occur in the unopposed muscles, preventing correction of the deformity At the same time, the paralyzed muscles lose their tone and elasticity If proper treatment is neglected during convalescence, the nerve may recover but there still will be a functionally useless limb because of the development of a permanent deformity which interferes with effective muscular activity

Objectives of Treatment

It is very necessary to emphasize the fact that degeneration of muscle begins immediately after injury Treatment, therefore, should be inaugurated at once and should be continuous. The objects to be achieved are (1) in cases of recent injury prevention of deformity and restoration of function, (2) in cases of old injury wherein treatment has been lacking, correction of deformity and development of any remaining function.

Preoperative Mechanical Treatment

This is as valuable as postoperative mechanical treatment. In each instance the aim is the same namely to prevent deformities and to maintain mobility and nutrition of the injured extremity If for example, the elbow is permitted to become ankylosed, operation and end to-end approximation of the nerve may not be possible because the elbow cannot be brought into full flexion to permit approximation of the nerve ends. Therefore, it is important to maintain the mobility of the various joints of the extremity and to prevent contractures and adaptive shortening of the unopposed muscles. If muscles have been allowed to contract and to become fibrosed, if scars bind down important tendons, and if joints are ankylosed, successful suture may be thwarted. There is scant use for the innervating mechanism if the machine itself is wrecked. Occasionally preliminary work and even corrective surgical measures may be necessary before operation on the nerve is undertaken.

more successful in preventing neuroma formation than any of the other methods ordinarily employed" To prevent ascending neuritis and to close off the nerve end, Conner (1918) formed a "swinging-door flap" by suturing the epineural edges. Closure of the nerve end, it is believed, is worth while, and is to be recommended when used in conjunction with injection of alcohol above the plane of section, whenever nerves of any size are cut

NONSURGICAL CARE FOLLOWING INJURY TO NERVES

The care of nerve injuries involves two problems first, the care of freshly wounded persons and of patients after operation, second, the late care of neglected patients who present muscular contractures and deformity In one case treatment is preventive, in the other, corrective Many neglected patients may require secondary operative procedures

Effect on Muscles of Interruption of Nerve Function

On interruption of nerve function, the following effects on muscles are observed (1) tone and contractility are lost, (2) atrophy sets in due to lack of voluntary action and to alteration in nutrition, (3) deformity develops due to stretching of the paralyzed muscles and to contracture of the opposed healthy muscles

Loss of Tone—Muscular tone is a condition of normal tension of muscular fiber due to the integrity of the reflex arc When the nerve is completely cut the tone of the muscle disappears and the elasticity of the group of muscles is lost. By preservation of the normal tone of opposing muscles, which maintains them in a state of slight contraction, paralyzed muscles become stretched and very soon lose the power to regain this normal tone Hence, there is great need to prevent overstretching due to faulty posture during convalescence

Loss of Contractility—Contractility is the power inherent in normal muscular tissue of contracting under stimulus Direct mechanical stimulus will arouse this contractile power, but the normal stimulus is effected by a nervous impulse The integrity of the muscular protoplasm is dependent on the presence of intact nerves A paralyzed muscular fiber rapidly loses its normal chemical and physical characteristics even though the muscle is exercised by mechanical or electrical means But such exercise will improve the nutrition of the muscle and lessen the periarticular contractures and adaptive shortening of the opposed muscles

measures improving general health and local circulation. If a nerve has been resected and so shortened that suture is possible only after relaxation by flexion of the limb, great care should be observed not to tear the suture line by failure to maintain proper postural flexion for a sufficient time after the operation. It may be advisable to immobilize the part for two to eight weeks or more. Later motion should be attempted gradually, and each movement should be controlled carefully. Fortunately, if the exercise is carried on gently and slowly enough, a nerve appears to be capable of very considerable stretching without being harmed.

After they have been damaged and repaired, nerves regenerate from their proximal ends through proliferation of the neurons. There is danger of damage to the nerve as it grows through light granulation tissue at the site of repair. Therefore, the need for careful avoidance of trauma at the seat of active proliferation must never be forgotten. Even after fairly active treatment of neighboring structures has begun it is well to allow several weeks of consolidation before beginning local treatment about the seat of suture. Hemorrhages in the newly formed tissue may lead to injurious cicatrization.

When the early stage of repair is past, and growth of the nerve is well under way, further treatment directed specifically to the nerve itself is unnecessary. Then begins the important period of the treatment. This concerns itself with the treatment of *muscles, tendons,* and *joints.*

Too much stress cannot be laid on the importance of thorough understanding of all the measures at the surgeon's disposal for after care in these critical cases. An appreciation of the relative value of various methods is very necessary for their successful use. Proper sequence in their employment and the amount of time to be devoted to each should be carefully understood, for as much harm may be done by their overuse as by their neglect.

METHODS AND DEVICES EMPLOYED IN NONSURGICAL CARE

Preventive Splinting

Rest in splints which hold the part in an overcorrected position is essential to prevent deformity of recently paralyzed muscles. The position given by Sir Robert Jones, and perhaps most generally accepted, is one of maximal overcorrection with the paralyzed muscles completely relaxed.

Types of Splints.—The standard splints supplied by the Army medical service will be found sufficient for most requirements. Adaptations of these to meet particular needs will suggest themselves

The methods of preoperative treatment employed are protective and corrective splinting, and the various forms of physical therapy These will be taken up after a few paragraphs have been devoted to postoperative care in general

Postoperative Care

Amid the abundant literature on nerve surgery which the war of 1914–1918 produced, one is struck by the meager attention given to after-care With the shifting personnel of military hospitals, too often a surgeon never has a chance to follow a sufficient proportion of his patients to develop an intelligent and systematic scheme of after-care Interest in operating also has diverted surgical interest from the more prosaic but no less important subject of convalescence

Importance of Continuous Care—The technic of operations on wounded nerves undeniably requires a high grade of surgical skill, but the contribution toward functional restoration made at the time of operation may be completely nullified by lack of subsequent care For example, in a case of paralysis in the distribution of the musculospiral nerve, if the wristdrop is allowed to continue during the many months of regeneration of nerves, the extensor muscles will be overstretched and, though the nerve may completely recover, contraction of the overstretched muscles will not take place until they have been thoroughly relaxed by proper splinting to overcome the wristdrop Thus, the operation is worthless, and the functional result may be a complete failure It is well to fix in mind at the outset of any study of nerve surgery that results differ radically from the brilliant results of most operative work which, when successful, yields to patient and friends almost immediate evidence of improvement It is discouraging to undergo a tedious operation, with the knowledge that even if it is a complete success its results will not be evident for from six to twelve months The suspense of waiting those many months for the decision as to whether the effort is to prove a success at all is a grueling test of fortitude for patient and surgeon alike (Table 2)

The regeneration of sutured nerves requires, roughly, a year or longer, and the surgeon's hardest task is to maintain his own and his patient's enthusiasm during the long convalescence Continuity of treatment is of the utmost importance Relaxation of effort for a week may undo the constructive work of many weeks

Care of Repaired Nerve—There is comparatively little to do for the repaired nerve other than to prevent immediate postoperative injury due to rough handling and to favor growth of the nerve by

splint which rests on the body a right-angled arm piece runs outward at the axilla in a plane a little anterior to the coronal plane of the body and on this rests the arm. The splint supplied for the Army—Jones' abduction arm splint—is well adapted to the purpose, although plaster with a wire arm piece is perhaps more commonly employed and is both comfortable and efficient.

MUSCULOCUTANEOUS NERVE.—Paralysis of the anterior muscles of the upper part of the arm prevents flexion at the elbow and results in stretching of the biceps if the supinator longus, supplied by the musculospiral (radial) nerve is also paralyzed. If the biceps only is involved, the flexor action of the supinator longus makes splinting unnecessary If both muscles are involved, the elbow should be held at right angles by means of a Jones right-angle elbow splint with hand piece for support of the hand in flexion, extension, supination, or pronation, as desired. It is, of course, necessary to provide ambulatory patients with a sling to give comfortable support to the apparatus.

MEDIAN NERVE, ULNAR NERVE.—These nerves supply the flexor muscles of the forearm. When paralyzed, the tendency will be toward hyperextension of the hand on the wrist and of the fingers on the hand. To offset this a splint should be worn to maintain the hand and fingers in flexion. A reversed, short, cock up splint, with a ball or a roller bandage held in the palm of the hand, will serve. A light plaster splint is more convenient and is easily removed and replaced when necessary The hand should be kept in supination, since fibrosis of the pronator places the hand in poor functional position. The pronated hand is a useful hand the supinated hand is not.

MUSCULOSPIRAL (RADIAL) NERVE.—Loss of the musculospiral nerve results in paralysis of the extensors of the arm, forearm, and hand. Hyperextension of the wrist is necessary This is secured by application of a cock-up splint. Various types are available, but the small, wire, cock up splint of Buerki is best adapted for this purpose (FIG. 31) It should be long enough to reach to the proximal interphalangeal joints.

SCIATIC NERVE.—In this lesion footdrop is the outstanding deformity as it is in injury of the external popliteal or peroneal nerve. This deformity may be handled by an outside iron with a strap so placed as to prevent footdrop, or preferably by the small, inexpensive wire splint of Buerki (Fig. 53) At night, a light posterior splint must be worn to prevent footdrop when in bed and to keep the weight of the bedclothes off the foot.

to the surgeon These splints have been adopted after much critical study and embody the results of three years of evolution of splints in the British and French services It must be distinctly understood that they do not represent the only good splints, but merely one simple and efficient set suited to most of the purposes for which splinting is necessary In addition to these, plaster-of-paris is a most useful splinting material and one of great value in meeting the need for unusual postures often demanded in the after-care of patients with nerve injuries Light-weight material is very important in providing splints They are used for protection of paralyzed muscles and not as orthopedic appliances to support the weight of the body Pressure of straps over paralyzed muscles must be avoided Since the appliances must be worn over long periods and many of the patients are, of course, ambulatory, this principle must not be carried so far that durability is in any way sacrificed Ease and speed in application are very desirable, since splints must be removed frequently for massage and other treatment

SPLINTS FOR ALTERATION OF POSTURE—Much ingenuity has been expended in the invention of adjustable splints fitted with hinges, turnbuckles, springs, or other recognized mechanical devices for altering position or tension In general, these types will prove disappointing Springs are rarely of great value and their use is always attended with some risk. Adjustable mechanisms are prone to disabilities of their own and, in a busy ward, are difficult to keep in constant repair Of far more general service is the rigid splint which can be bent to a set contour and altered from time to time by further bending or by the gradual addition of felt or sponge-rubber padding as alteration of posture is secured It is very desirable to arrange an apparatus for ambulatory use of all patients so far as possible because of the long period necessary for convalescence

Application of Splints—Each case will present its individual problem and will call for special modification in the use of splints, but the following principles of treatment may be of service in approaching the more frequent types of paralysis

CIRCUMFLEX (AXILLARY) NERVE—Injury to the circumflex nerve results in sagging of the shoulder under the weight of the arm and the power of abduction is lost The arm should be maintained in a position of abduction at right angles to the body To accomplish this, a splint molded to the trunk is necessary, and it should take its bearing from the crest of the ilium on the affected side, otherwise it will slide downward when the patient is in the upright position, and lose its efficiency From the portion of the

It is of great importance to gain the cooperation of the patient himself by explaining the purpose of the splint and the necessity for continuous treatment; otherwise he may loosen splints at night and retard his own recovery.

Physical Therapy

Fortunately there is a considerable variety of physical procedures, all of much value. Various physical measures are desirable when one takes into account the length of time required for treatment for peripheral nerve injuries and the problem of keeping the patient contented during so long and tedious a period. The health of motor tissues depends on use. Degeneration follows either paralysis or simple disuse. The repair of diseased organs is a nutritional problem. Hence, the physical procedures, exercise and methods of producing hyperemia, are useful. There are other elements that may make the treatment more effective as, for example, a mild suggestion to the patient regarding the mysterious powers of electricity when it is desired to maintain his interest for a long period of electrotherapy. The physician should beware of the easy self-deception that enthusiasm for a special method produces, and should attempt a fair evaluation of all recognized methods and train himself in a rational use of the different varieties.

Thermotherapy.—Heat is a recognized therapeutic agent for the production of hyperemia. The particular form of heat probably has less significance than the duration of its application and the temperature reached. Hot water, hot air, and electric heat are all useful; the last is of widest application because of its convenience. Actual temperatures in the heat chamber may be very high, the evaporation immediately about the skin preventing burning. The small, portable electric light heaters may be applied conveniently to any part of a limb. In the treatment of peripheral nerve injuries the chief value of thermotherapy is in preparation for massage. It is to be remembered that a part of the limb may be anesthetic; hence, great care must be exercised to prevent burning.

Hydrotherapy.—Baths and general hydrotherapeutic measures have been used with great success in the management of peripheral nerve injuries. In addition to the usual tub, sitz, and shower baths, there are such hydrotherapeutic measures as sprays, whirling baths with and without aeration, and so on. The object is stimulation of circulation by means of heat or contrasting heat and cold and by means of the mechanical effect of moving water on the skin. There is no doubt of the invigorating effect of hydrotherapeutic measures

All the splints should be comfortable and worn constantly, save when treatment and passive exercises are being given During the late stages of convalescence they should be removed gradually, at first for short periods during the day, when the patient is allowed active exercise They should be worn at night for a prolonged period after recovery is well advanced. The gradual removal of splints usually will be continued for many weeks or months, and it is most important to keep the patient under observation during this period of splint removal, as contractures may occur long after recovery of muscular power and tone is apparently complete

Corrective Splinting

In an old deformity resulting from paralysis in the region of distribution of a nerve, three tissues enter into the contracture: ligament, tendon, and muscle Ligaments are nonelastic, muscle possesses elasticity Care must be taken that nonelastic tissue is not unnecessarily torn by efforts at forcible correction On account of nutritional changes, affected structures undergo atrophy and become less resistant to trauma There is danger of rupture of ligaments and even of avulsion of bone at the point of ligamentous attachment. For this reason, nonoperative correction of deformity is always preferable in cases in which this method is feasible It is a slow and often tedious process, but it eliminates the danger of injury to atrophic muscle, ligament, and bone, which may occur from rough handling under anesthesia Many patients have been through several operations and would themselves prefer a slower convalescence to further surgical interference

If proper patience is exercised, successful correction of extensive deformity may be accomplished by gradual stretching of contractures with splints The initial selection and fitting of the splint is of great importance, and accepted principles of application of splints must be kept constantly in mind. Corrective pressure is borne by soft tissues, and the amount that can be applied is limited Constant watchfulness is required to avoid necrosis of skin or other tissues The splint should be removed at frequent intervals and regular physical treatment given both for the purpose of forestalling injury by pressure and to increase pliability and local circulation Cutaneous sensation may be absent or lessened, and many patients are uncomplaining The vigilance of the attending surgeon should be constant to assure as rapid correction as the skin resistance will permit. Adjustments left to the control of the patient are unwise, and the judgment of nurses and orderlies must not be trusted too implicitly

in hastening the wounded man along the road toward the complete restoration of voluntary motion.

Electrotherapy.—During the war of 1914–1918, the use of electricity received much attention and achieved excellent results in treatment of the after-effects of injuries to the peripheral nerves, of injuries to the joints, and of functional nervous conditions. Many of the methods of application advised require complicated apparatus and a considerable degree of skill and experience in those who administer them. In the following pages only the more commonly used methods will be discussed. The following forms of current are used: the constant or galvanic, the induced or faradic, the sinusoidal, and the high-frequency.

Constant Current.—This is one which flows constantly from the positive pole, or anode, to the negative pole, or cathode, as long as the circuit is closed. It therefore always passes in one direction. The source of supply may be either a battery composed of twenty or more dry cells, or what is preferable when possible, an electric light circuit. If this is alternating, it must be rendered unidirectional by a suitable converter. There must be a means of gradually increasing and decreasing the strength of a current. If possible, a milliammeter should be in the circuit. A switch by which the current can be opened or closed and one by which the polarity can be reversed are essential.

If either pole is active it will cause muscular contraction, but to do so the circuit must be suddenly opened or closed. If the current passes without interruption or is gradually increased or decreased in strength, no contraction occurs.

Faradic Current.—This is characterized by more or less rapid alternations and a momentary *interruption* of the current. When possible, it is well to have an apparatus that allows both slow and rapid interruptions. A simple make-and-break type of inductorium will serve. This current has no polar influence, as has the galvanic, and its principal use is as a means of exercising weakened muscle in which there is no reaction of degeneration. It must be remembered that it will not cause contraction of muscles that are paralyzed owing to a lesion of the peripheral neuron.

If the rapidly interrupted current is employed, more or less tonic or tetanic contraction is caused. The current slowly interrupted gives clonic contractions.

Many emphasize the importance of this means of maintaining and increasing the nutrition of the affected muscles, as well as exercising them and preventing adhesions in tendon sheaths and

when they are judiciously employed and, here again, they are valuable as a preliminary to massage

Massage—Massage is a useful and generally applicable method of physical treatment in these cases Many devices have been invented with the thought that they might supersede the human hands as instruments of massage, but without success Attention should first be paid to maintenance of the nutrition of paralyzed muscles The overlying skin, which is often atrophic, may benefit from the treatment as much as the muscles As was explained in discussing the pathology of nerve repair, great gentleness should be practiced by the masseur during the early stages of work with recent nerve injuries Effleurage and wholly passive movement are followed gradually by more vigorous exercise Splints are temporarily removed for this treatment. Work should be done with the paralyzed muscle relaxed and the deformity overcorrected, and the patient's position while being massaged must be wisely planned For example, when there is wristdrop, the hand should be held in supination, and when there is paralysis of the median and ulnar nerves, the hand should be pronated In involvement of the circumflex nerve, the patient should be lying on his back and the arm should be raised beyond a right angle in abduction Likewise when there is footdrop a prone position, with the foot hanging over the edge of the table, will lessen the tendency toward plantar flexion, or the patient may be made to support the foot at right angles by holding the ends of a bandage looped about the toes

The selection of efficient operators is a matter for careful consideration Not only should masseurs be well trained and experienced, but they should not be expected to undertake the treatment of too many patients in a day It has been found that one operator can care for about fifteen patients If more than twenty are assigned to one masseur the quality of his work is likely to deteriorate noticeably

Corrective exercises should follow the gentler forms of massage Force should be wisely graduated Much damage may be done through the use of too vigorous methods Resistive and assistive exercises are of great benefit in the development of muscular strength and in the reeducation of the patient in the use and control of the muscles

Finally, it is the duty of the masseur to follow up the patient even after he has recovered sufficiently to begin active exercise and training in the curative workshop At this time supplementary massage and careful direction of exercises is often of great assistance

cause their employment makes it difficult to keep up the patient's interest, and it is hard to induce him to give them the constant use required to make them serve their intended purpose.

Far better results have been obtained by expansion of the principles of curative workshops described below

CURATIVE WORKSHOPS.—Very important among these types of treatment is that of curative workshop training as distinguished from the purely vocational training which belongs to a later period and aims at such different ends, and by such dissimilar methods, that it should be kept apart from the former in time if not in place as well. Curative workshop training should be instituted at the earliest moment physically possible, often even while the injured person is still a bed patient. Vocational training is to be employed only when the curative workshop training, in connection with other purely therapeutic measures, has restored as fully as possible all the functions of the members lost or impaired by the injury

1 Aims of Curative Workshop Training.—The aims of therapeutic or curative workshop treatment are, roughly threefold (1) to keep the mind of the patient occupied by interesting work during the many months of convalescence, especially at first when he is likely to spend his time pondering over his hopeless, helpless lot, (2) to restore the habit of work which is so frequently lost during the period of suffering and discouragement associated with any long course of hospital treatment; (3) to obtain the greatest possible range of usefulness to structures directly or indirectly affected by the injury in other words, both mental and physical reconstruction.

For these reasons, curative workshop treatment should be instituted in modified form as soon as operative procedures, splints, and dressings permit.

Certain types of work can be carried out in bed if a hand or hands are available in any form. A few hours daily on a piece of embroidery or knitting which is of interest to the patient will accomplish infinitely more in preserving or restoring function of the fingers or wrist than the routine use of various forms of mechanotherapy which involves the use of an elaborate machine taken in rotation for a few moments each by a series of patients.

2. Types of Work.—The shop should be furnished with electric power and should be divided into sections to give a reasonable variety of occupations. Whereas some power-driven machinery such as lathes, drills, and so forth, are advisable in order to make the production of metal splints and other hospital equipment possible, the simpler the workshop tools and apparatus, and the more easily

joints However, there is need for experimental work to show the actual value of the various forms of electrotherapy In injury of the spinal cord, if the cord is not completely divided, exercise of the paralyzed muscles may sometimes be of service In cerebral injury with resulting hemiplegia, faradic stimulation may be useful, and then as a rule it should be applied only to the extensor muscles, as by so doing contractures may be prevented or lessened

HIGH-FREQUENCY CURRENTS—These are produced by discharging one or more condensers through a coil of wire An electric-light circuit is used, the current of which is stepped up by a transformer The current alternates or oscillates at a very rapid rate An induction coil may produce a current which oscillates several hundred times a second, whereas the high-frequency or diathermy currents oscillate at a rate of 500,000 to 300,000,000 times per second

One of the peculiarities of these currents is that the neuromuscular mechanism of the human organism does not respond even when a current strength of one or more amperes is used With currents of lower frequency this amperage might be fatal The practical value of the high-frequency current in surgical cases results from the fact that they possess the power to produce local hyperemia by heating the tissues deeply If used properly they produce no sensation other than that of heat.

The heat obtained from this high-frequency or diathermy apparatus differs from that obtained by other means of heating the body in that it penetrates the tissues more deeply

Diathermy may be used to warm paralyzed limbs that are cold and cyanotic, but because of the danger of burns if there is any impairment of sensation, it must be employed with great caution if at all

IONTOPHORESIS OR COMMON ION TRANSFER.—The power of the poles of the galvanic current to cause diffusion of various medicinal ions from them and to cause these ions to pass through the superficial layers of the skin has been utilized in medicine Ions of iodine, histamine, and salicylic acid have been so used in the treatment of neuritis and injured nerves, but they are of little value and the procedure may cause dangerous burns if sensation is impaired

Mechanotherapy—Many forms of mechanical apparatus have been devised which are designed to bring into play various groups of disabled muscles and thus increase their functioning capacity While some of the simple forms are of distinct advantage, the results obtained have not justified the building of extensive equipment be-

CHAPTER V

INFECTIONS OF NERVOUS SYSTEM AND ITS COVERINGS ARISING FROM INJURIES OF WAR

CHARLES BAGLEY Jr., M.D., FRANCIS C. GRANT M.D., and GILBERT HORRAX, M.D

INFECTIONS OF SCALP

THESE infections arise from nontreatment or improper treatment of wounds of the scalp The inflamed region may be localized around the injury or diffuse, boggy edema of the whole scalp may be present. If infection is extensive there may be swelling of the forehead and eyelids.

The continuous application of hot wet dressings and institution of adequate drainage are the two methods of local treatment. If infection is localized, drainage can be obtained by the making of a linear or T-shaped incision within the circumscribed region. If infection is extensive, with generalized edema of the scalp counter incisions should be made in portions in which pus is likely to be obtained or to which it would gravitate *Sulfathiazole powder* should be used freely within the opened region.

Cultures of material obtained always should be made and the appropriate form of chemotherapy should be instituted by mouth, but even before the type of organism present is known a course of *sulfanilamide* should be started (see "Meningitis," p 186)

The patient should be watched for symptoms which would indicate a spread of the infective process of the scalp to the underlying bone or brain.

OSTEOMYELITIS OF SKULL

In the presence of infections of the scalp in which drainage has been instituted or in the presence of compound fractures of the skull, evidence that general sepsis is afflicting the patient or local evidence of infection in the region of injury is a clue that osteomyelitis may be developing. Once started it may extend until huge portions of the skull are involved. In the early stages of such a process re-

their use can be grasped by the patient, the better. Carpentering, cobbling, leather working, cabinet work, tailoring, wood carving, fretsaw work, leather embossing, metal work (especially for apparatus and splints), printing, weaving, basket-making, as well as typewriting and bookkeeping, represent some of the most satisfactory types of work

The surgeon in charge of the patient should perscribe the general type of exercise desired to be obtained in the workshop, based on the condition of the structures involved The administrator of the workshops will order the most suitable type of work to obtain these results, varying the .type of work in accordance with continued observation of the patient's mental and physical capacity

Whenever individuals skilled in any particular occupation are found among the patients, if their general treatment will continue over a long period they should be used as instructors in the workshops, supplementing the instructors A certain number can be used for clerical work Noncommissioned officers who are patients are frequently very useful in matters of discipline when put in charge of the men in workshops

3 *Allied Treatment*—*During the period of treatment* in the workshop the importance of other treatment ordered by the surgeon in charge of the case, such as massage, electrotherapy, and so forth, should not be overlooked Appointed hours for such treatment should be arranged to fit in with the workshop hours in such a way as to cause as little delay and confusion as possible

4 Preparation for Vocation—Curative workshop treatment should continue as long as there is possibility of any marked physical improvement from such treatment During this period the patient should be studied by the vocational director with a view to the permanent vocation to be recommended and in some cases the curative work can be directed toward that end Purely vocational therapy, however, belongs to the following stage of the treatment, when facility and capacity for the special line chosen can be freely developed

This following stage the formerly helpless, disabled, and discouraged soldier now can approach with a feeling of confidence and a hope for the future which would have seemed impossible before curative workshop treatment was first undertaken

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sults of roentgenograms may be negative, but when the condition is well developed the "moth-eaten" roentgenologic appearance of one or both tables is easily recognizable.

Treatment

Early removal of a small portion of bone affected by osteomyelitis in a compound fracture of the skull often will prevent spread of the condition through the vascularized bone

Radical Excision—If the infection is already widespread, only the most radical type of treatment is indicated This consists in surgical excision of the entire portion of the skull involved, even though this portion is a half or two-thirds of the cranial vault Bone should be removed to such an extent that the remaining contiguous bone appears to be normally vascular Removal should be done as soon as the diagnosis is made, regardless of the degree of deformity which will result, since the operation is a life-saving measure Removal is best accomplished with heavy, double-action rongeurs, or by the procedure in which bur holes and the Gigli saw are employed

When removal has been completed, the whole region is packed widely open, preferably by the placing of a large piece of smooth material, such as rubber sheeting or gutta-percha, over the denuded surface and then gauze over the rubber or gutta-percha If these materials are not available, vaselined gauze may be used *Sulfathiazole powder* should be dusted over the whole denuded region.

The periosteum over the osteomyelitic bone as a rule can be preserved, and in some instances it can be resutured and appropriate and adequate rubber drains can be left in place between it and the dura The skin flaps which have been made to secure exposure of the bone likewise can be drawn together loosely, and drainage with rubber drains again can be instituted. Partial closure such as this will save time, but care must be exercised and the wounds must be watched for any possible pocketing of pus

Plastic repair of large defects, when it is necessary, should not be undertaken for a year after the original removal of bone

As in all infections, the proper form of *chemotherapy* should be employed, depending on the type of organism present as determined by culture A discussion of these matters will be found under "Meningitis," in the next main section of this chapter

MENINGITIS

Infection of the meninges may develop from any type of compound fracture of the skull or penetrating gunshot or shell wound

of the brain. It is, however particularly likely to result from injuries which traverse the frontal or ethmoidal sinuses, or from basal fractures in which the tympanic membrane has been ruptured. In all such injuries it is of the utmost importance that chemotherapy be instituted at once and as vigorously as the patient's condition will permit.

Diagnosis

The diagnosis of meningitis is presumptive at any time during the patient's course after a compound fracture of the skull or a spinal fracture, if headache, stiffness of the neck, presence of Kernig's sign, and possibly chills are accompanied by a sudden increase in temperature and leukocytosis. The diagnosis is absolute if lumbar puncture produces a cloudy or purulent cerebrospinal fluid, culture of which is positive.

Delirium frequently is a sign of meningeal irritation and it usually appears early Drowsiness, stupor or coma may supervene. Periods of restlessness and stupor may alternate. The reflexes are variable.

Whenever there is the slightest clinical suspicion of meningitis, the spinal fluid should be examined. Lumbar puncture should be performed and the pressure of the fluid should be measured with the patient in the horizontal position. Specimens should be obtained for cell count and determinations of total protein and sugar In the presence of meningitis the cerebrospinal fluid may be slightly turbid, xanthochromic, or markedly cloudy to the point of containing frank pus. Pressure of the fluid ranges from normal to extremely high values (that is, 400 to 500 mm. of water) The number of cells ranges from several hundreds to as many thousands. Polymorphonuclear leukocytes predominate in the usual pyogenic types of meningitis.

Lumbar puncture in addition to being employed as a diagnostic measure, should be carried out at least once or twice daily for therapeutic purposes. If the pressure of the fluid remains high (300 mm. or more) puncture should be done probably as often as every eight hours.

In the presence of all forms of meningitis the primary focus should be dealt with adequately so far as removal or drainage is concerned, and *sulfathiazole powder* should be used locally

Chemotherapy in Meningitis

Staphylococcic Meningitis.—For staphylococcic meningitis *sulfathiazole* is the drug of choice. For intravenous administration a 5 per cent solution of the sodium salt of the drug, freshly dissolved in warm

distilled water, should be used Three gm is given as the initial dose, and is followed by 1 gm given every eight hours Oral administration of the drug should be instituted as soon as it is feasible If the drug is administered orally from the start, 3 to 6 gm can be given initially, followed by 1 gm given every four hours

In addition to sulfathiazole, *staphylococcic antitoxin* administered intramuscularly or intravenously is a worthwhile adjunct The dose for an infection as severe as meningitis is from 10,000 to 20,000 units early during the first day in divided doses, followed by from 10,000 to 20,000 units daily until the desired effect has been obtained

Streptococcic Meningitis—For streptococcic meningitis *sulfanilamide* is the best chemotherapeutic agent. The drug should be given by mouth when this is possible An initial dose of 3 to 6 gm should be followed by 1 gm administered every four hours to the point at which an average daily dose of 6 gm is obtained. An equal quantity of *sodium bicarbonate* should be given with the drug If oral administration is impossible, 300 cc of a 1 per cent solution of the drug in physiologic saline solution should be infused subcutaneously every twelve hours

Pneumococcic Meningitis—For pneumococcic meningitis, *sulfapyridine* is the chemotherapeutic agent. Specific *antiserums* also may be used. If sulfapyridine is given intravenously, the initial dose should be 0 05 gm per kilogram of body weight. Thereafter, half this dose should be administered every eight hours until clinical improvement and improvement of the condition of the spinal fluid have been obtained. If the drug can be tolerated when it is given by mouth, 6 to 8 gm of it should be administered per twenty-four hours in broken doses The drug likewise may be given by hypodermoclysis, in which procedure a 0 5 per cent solution of sodium sulfapyridine in physiologic saline solution is given in doses of 6 to 8 gm per day Since relapse is common in pneumococcic meningitis, chemotherapy should be continued until the clinical course of the patient indicates clearly that the infection is under control.

ABSCESS OF BRAIN

Abscesses involving the brain may be extradural or epidural, subdural or intracerebral. The last named is by far the most common form with which the surgeon has to deal as a result of penetrating bomb, shell, and gunshot wounds The problem of diagnosis, localization, and treatment of a post-traumatic abscess of the brain differs not at all from that encountered when such an abscess is consequent on any other source of infection. In one respect the solution may be

easier for a history of injury to the head, together with certain details as to the site and type of injury, usually is at hand, and calls prompt attention to the possibility that an abscess may be the cause of the patient's symptoms.

Epidural and Subdural Abscesses

After cranial trauma an acute abscess of the brain most frequently develops if at the time of injury a compound fracture occurred.

In Absence of Dural Penetration.—If the dura has not been penetrated, the pus in most cases will be *extradural*. Within three to five days local evidence of infection of the wound may be present, plus an increase in temperature. Pulse and respiration are unlikely to be affected. Headache is outstanding. Tenderness to percussion over the adjoining cranial vault is common. Slight stiffness of the neck may be noted. A mild increase in leukocytes is recorded. If the abscess lies over an active cortical area, such as the motor cortex, contra lateral reflex changes or more rarely muscular weakness or a con vulsive attack may be observed. If lumbar puncture is performed (and if this is done, no more than 0.5 cc. of fluid should be removed for cell count and estimation of pressure) an increase in leukocytes is to be expected. Roentgen-ray studies usually are of little value unless the case is one in which the inner table has been much more widely fractured and depressed than the outer table and hence was not inspected or noted when the wound previously was explored.

TREATMENT.—Immediate reoperation and drainage must be per formed, with removal of all involved bone. The incision in the skin should be left wide open, light packing should be introduced, and intermittent lavage with suitable antiseptic solutions (Dakin's solution, acriflavine 1 1000 solution, disodium salt of 2 7 dibromo-γ-hydroxymercurifluorscein [mercurochrome] 2 per cent, alcohol solution of gentian violet 1 per cent) should be instituted. If a streptococcus can be isolated from the pus, *sulfanilamide* administered orally or otherwise in proper amount should be used (see "Meningitis," p. 186) The powder likewise should be used locally at the site of infection.

In Presence of Dural Penetration.—If at the time of the initial injury the dura was penetrated, the resulting acute abscess may be *subdural* or *intracerebral*. The symptoms appear at about the same time the injury was sustained or twenty four to forty-eight hours later and differ as a rule in degree only When the abscess forms, headache is more severe and meningismus is more marked. The temperature is elevated and, if the infection be intracerebral, pulse and respiration

may be retarded in comparison to the febrile reaction Vomiting may occur The patient may become delirious or stuporous. If the original injury resulted in much loss of bone or if fragments were removed during débridement the wound may bulge, suggesting intracranial pressure Cautiously performed lumbar puncture will reveal an increase in intracranial tension plus an *increased cell count* due to the increase in number of leukocytes The neurologic signs will depend on the position of the abscess *A collection of pus forming* in or near the motor cortex may give rise to hyperactive and pathologic reflexes contralaterally, focal convulsive seizures, or weakness or paralysis of the face or extremities Roentgen-ray studies should be made to determine whether or not a foreign body, which may have been overlooked when the wound was explored, is present in the brain

TREATMENT—Subdural abscesses are evacuated by removal of bone and wide incision of the dura over the collection of pus Adequate drainage should be insured, either by placing of several rubber tissue or similar drains or by packing the region lightly but widely open, first placing some smooth material like rubber dam next to the surface of the brain and then gauze soaked in a mild antiseptic solution, above the smooth covering Dry or wet gauze never should be placed next to the brain Dakinization is advisable, together with the local use of *sulfanilamide powder* A cerebral fungus will form slowly, forcing out the gauze When this fungus reaches the level of the skin, lumbar puncture should be done to reduce intracranial tension and the size of the hernia When the hernia has receded, the margins of the skin are drawn back over it. The wound is allowed to heal by granulation

Intracerebral Abscess

The usual type of abscess of the brain is, as was said previously, intracerebral, it forms around some sort of foreign matter such as fragments of bone, hair, clothing, or metal which has been driven in as a result of a war wound Such abscesses therefore are most likely to develop when the tracts produced by missiles within the brain have been incompletely cleaned out. They are less likely to form around metallic foreign bodies than around other material, but every retained foreign body of any kind nevertheless acts as the potential seat of an abscess of the brain

Symptomatology of Brain Abscess

The signs and symptoms of abscess of the brain are, first, those of *infection,* followed later by evidence of *increased intracranial pres-*

sura. They may develop at any time after injury from a few weeks to many years, but probably arise most frequently between three and six months. *Headache* is a very constant accompaniment and, although it may be intermittent, it is present in all stages. *Vomiting* is associated with the headache, but varies with the degree of increased intracranial pressure, except in the case of cerebellar abscess, in which vomiting occurs as an early irritative sign. The *pulse rate* during the early period generally is rapid, but is almost invariably slow after encapsulation of the abscess has been completed. *Convulsive seizures* are frequent in the early period and may occur at any stage. They may be focal or general in type, depending on the site of the lesion. The *optic disks* may show slight changes as a result of cerebral edema in the early stages, in the later stages a severely choked disk with hemorrhages is the rule. Leukocytosis is present, but disappears after complete encapsulation has occurred. The range of temperature likewise is high during the first stage and low during the second. In the beginning *cerebration* is slow and there is gradually increasing stupor leading to coma in the second stage. *Delirium* seldom occurs unless there is associated meningeal inflammation.

Clinical Course.—The clinical course of the disease, therefore, may be divided into three stages. *First* occurs diffuse infection involving a limited part of the brain or brain and meninges, with evidences of systemic infection, such as elevation of temperature, rapid pulse, and leukocytosis, with or without focal neurologic signs. Headache and vomiting, frequent muscular twitchings, and even convulsive seizures may occur The optic disks exhibit little or no change. After the invasion, the infection may spread rapidly through the brain or meninges or it may be encapsulated.

In the *second* stage, that of encapsulation, the patient is afebrile and without other evidence of systemic infection. Signs of increased intracranial pressure, headache vomiting, slow pulse, choked disk, and stupor, with or without localizing signs, depending on the situation of the abscess, characterize this stage.

In the *third* or terminal stage, the abscess if untreated produces symptoms of fatal pressure or the capsule ruptures with the escape of pus into the meninges, ventricles, or substance of the brain. After such rupture the course again is febrile.

Diagnosis and Localization of Chronic Post traumatic Abscess of Brain

Strictly speaking, every abscess of the brain passes through an acute stage which later may become chronic. War statistics as well

as experience with the injuries of the head seen in peacetime seem to show that if a patient can survive for three weeks after a compound fracture of the skull with or without meningeal penetration, meningitis or acute spreading cerebritis will not develop as a result of his injury After this time any infection will take the form of a chronic localized abscess

A common story is roughly as follows. A month or six weeks after the initial injury, with the wound completely healed or with a small draining sinus present, the patient may begin to feel listless and out of sorts Mild headache gradually appears, increasing slowly in severity. Appetite is lost and bowel function is impeded Depending on the situation of the abscess, neurologic signs, slight facial droop, weakness or clumsiness in the use of an arm or leg, difficulty in speech, particularly in the sensory sphere, visual impairment, indicated by an homonymous field defect, and ocular palsy may make their appearance The headache increases in intensity, and mental dulness and slow reaction time become more marked Percussion of the cranium frequently will reveal an area of localized tenderness, and examination and palpation of the scalp will disclose the evidence of previous injury The pulse is slow and the temperature tends to be subnormal The two symptoms consistently present in abscess are headache, general or localized, and a slow reaction time This clinical picture, plus the history of an injury to the head (usually penetrating in nature) should arouse strong suspicion of the presence of an abscess Certain other studies are essential. Determination of the visual fields always should be made before the patient becomes so stuporous as to impair the accuracy of the procedure Roughly, 60 per cent of patients suffering from chronic abscess of the brain will have papilledema on examination of the optic fundi Roentgen-ray studies may reveal an old fracture or a foreign body within the brain, more rarely, if a gas-forming organism is the source of infection, a bubble of gas may indicate the position of the abscess Studies of blood chemistry disclose mild leukocytosis, lumbar puncture (which must be done cautiously) reveals clear or very slightly turbid fluid that is under increased pressure and contains leukocytes if the abscess is still developing or a predominance of lymphocytes if the abscess has encapsulated Hyperalbuminosis is present.

If the general signs characteristic of abscess are present, such as headache, mental hebetude, vomiting, papilledema, slow pulse, and low temperature, and if the neurologic evidence is indefinite and inconclusive as to the position of the abscess, ventricular estimation or a ventriculogram should be made without hesitation Accurate local-

ization of the lesion is so important for successful surgical drainage that these procedures are always indicated if any question exists. The positive information thus obtainable offsets the slight hazard involved in these procedures.

Treatment for Brain Abscess

Diagnosis and localization having been made as accurately as possible (and accuracy of 85 per cent is easily attainable) certain matters concerning operative methods must be considered.

Premature Attempts at Drainage.—The first and most important considerations are the length of time the abscess has been present and whether or not the infectious process has become walled off and encapsulated. Certain abscesses never will become encapsulated but at least they will contain pus which can be evacuated. Evidence indicates that if encapsulation is to occur it will be present by the end of the third week after the onset of symptoms. No other single factor is more likely to lead to the death of the patient than an attempt to drain a subcortical infectious process before free pus has been formed. The only result of such a premature attempt at drainage is further extension of the cerebritis present.

Evacuation of Pus.—The surgical attack on an abscess must be made along the route by which the infection entered, through the previous wound, because the great majority of abscesses lie along the tract of the injury Here the subarachnoid space presumably has been obliterated by adhesions, and pus can be evacuated without the chance of the subsequent development of meningitis. With the patient under the influence of *local anesthesia* (which always should be used) an incision about 1 inch (2.5 cm.) long is made in the line of the scar A half-inch (about 1-cm.) trephine hole is made in the bone and the dura is penetrated or if an opening already exists, the scar is carefully incised until the cortex is reached. Surrounding meningocortical adhesions should not be disturbed and *only as much* of the cortex should be exposed as is sufficient to admit the tip of the exploring needle. This is the usual ventricular puncture needle, except that it is much longer than usual and has two large openings at each side of the tip, instead of fine perforations. The pus is at times so thick that it will not escape unless the openings in the needle tip are at least as large as the bore of the needle itself. The needle is now introduced along the tract of the previous injury A sensation of resistance similar to that which would be obtained if a rubber ball were being prodded by the needle tip will indicate that the capsule of the abscess has been reached. If the abscess has not become encap-

sulated, the needle may suddenly fall into a cavity and pus may appear at its outer end. The angle at which the needle enters and the depth at which the capsule is encountered or at which pus is obtained must be carefully recorded. If a capsule is encountered it should be promptly penetrated. The degree of force necessary to puncture it will provide a clue to the thickness of the capsule. About 4 or 5 cc. of pus is now allowed to escape and is carefully collected in a test tube, every effort being made to prevent soiling of the wound. Two cc. of a colloidal suspension of *thorium dioxide* (thorotrast) is injected into the cavity of the abscess and the needle is withdrawn. Escape of the pus relieves intracranial tension and the thorium dioxide will permit the size and position of the abscess to be identified on a roentgenogram. If a suspension of thorium dioxide (thorotrast) is not available, air or iodized oil (lipiodol) might be used.

While the pus is being smeared, stained for organisms, and cultured, roentgenograms are made. The smears will provide a clue to the type of the organisms present and the number of them conveys some conception of the virulence of the infection. Streptococci and staphylococci are the organisms most frequently encountered. If streptococci are identified, *sulfanilamide* always should be administered. Study of the roentgenograms will show the general position and size of the abscess and the most dependent point from which it can be drained. The force required to penetrate the capsule, as has been said, will suggest its thickness and also the degree of chronicity of the abscess. It is to be remembered, in the planning of dependent drainage, that the patient will spend his time on his back in bed for the next few weeks.

Surgical Methods.—Five methods exist for the surgical handling of an abscess of the brain.

METHOD 1.—Through a small trephine opening the abscess can be tapped and the pus can be drawn off on one or more occasions without the introduction of drainage.

METHOD 2.—Through this small trephine opening, after the abscess has been tapped, a fine, soft-rubber catheter can be inserted for drainage.

Methods 1 and 2 have the advantage that they drain the abscess with a minimum of trauma to the adjacent cortex and hence produce fewer serious neurologic sequelae to plague the patient in after-life. But drainage may be inadequate, an abscess with multiple cavities may not be completely evacuated by these maneuvers, and increased ranial pressure caused by edema about the abscess may not

be controlled unless contralateral subtemporal decompression is carried out at the same time.

METHOD 3.—A larger opening for craniectomy can be made (4 by 5 cm.), surrounding the original scar The dura then can be opened as far as the edge of the bone and the subarachnoid space can be obliterated by suture of the dura to the cortex, by electrosurgical coagulation, or by the packing of strips of iodoform gauze between the dura and the arachnoid. Cortical vessels are secured by ligature or coagulation and a cortical incision is made down to the capsule of the abscess. The capsule is then opened, pus is evacuated, retractors are introduced, the cavity of the abscess is carefully inspected so that the surgeon can be certain that no communicating cavities exist, and it is packed with gauze under direct vision. Instead of gauze a Mosher wire drain may be used. If the capsule of the abscess is very thick and if the abscess lies close to the surface, the capsule may be drawn up and sutured to the dura or skin, thus effectively shutting off the subarachnoid space and preventing the development of meningitis (marsupialization)

METHOD 4.—The abscess can be tapped and identified and then a fairly large bony opening can be made over it. The dura is opened widely and the subarachnoid space is protected by the placing of packs between dura and arachnoid. That part of the cortex which lies over the abscess is now completely excised and the abscess is unroofed. No packing at all is used except that employed to wall off the subarachnoid space. Intracranial pressure causes herniation of that portion of the brain which contains the abscess consequently the abscess is turned inside out, the bottom of the cavity finally forming the top of the fungus. Dakinization controls infection, and a too large protrusion of the fungus is combated by lumbar puncture. As healing occurs the fungus recedes, the flaps of skin are allowed to fall into place, and the wound heals by granulation.

METHOD 5—The possibility of complete extirpation of an abscess of the brain should be mentioned. In the presence of a heavily encapsulated post traumatic abscess this method perhaps gives the best chance for cure. In such a circumstance the capsule is so thick that tapping or tapping and drainage are unlikely to be efficacious. For extirpation of an abscess in this way a bone flap is elevated, the cortex is incised, and the abscess is enucleated as a whole, as a tumor is enucleated, without rupture of the capsule

RECAPITULATION OF METHODS.—As may be gathered from this brief review of the various methods suggested for the cure of abscess of the brain, much depends on proper interpretation of the observa

tions made at the original tapping, identification of the organisms, and the introduction of thorium dioxide (thorotrast) Given an abscess close to the surface, without a capsule, (1) simple *tapping without drainage* is indicated Later, after encapsulation has occurred, (2) *tapping and drainage* may be sufficient. Any abscess situated in a region in which cortical damage may result in unfortunate neurologic sequelae warrants inextensive trephining, simple tapping, or tapping and drainage as an initial procedure If this is not successful (3 and 4) *craniectomy*, protection of the subarachnoid space, and cortical incision down to or into the abscess seem the safer methods. (5) *Complete excision* after the making of a bone flap should be reserved for deep-seated, heavily encapsulated abscesses which will not collapse after drainage

Postoperative Treatment—Whatever form of drainage is used, the usual voluminous gauze dressing should be placed over the whole, and left in place without change for two days. Thereafter, dressing at one-day or two-day intervals should be done *Sulfathiazole powder* should be used freely within the cavity of the abscess, but not on any exposed portion of the brain *

As mentioned previously, there is always a tendency toward formation of a fungus around the site of the drainage tract. This may perhaps be combated successfully by lumbar puncture if it is done promptly at the earliest evidence of hernia of the brain Gradually, drains or tampons will be pushed out and should be cut off about every forty-eight hours, as protrusion occurs Granulation over the whole region occurs slowly and the whole exposed portion must be covered carefully with smooth tissue and gauze placed over this If a fungus has formed, its surface also will granulate, and as intracranial pressure recedes the fungus likewise will recede, leaving a flat granulating surface level with the bone Pinch grafts may be used on this surface to hasten epithelization.

EPIDURAL SPINAL ABSCESS

This disease occurs with sufficient frequency to warrant inclusion of it in a discussion of surgical infections of the nervous system, particularly since it constitutes a real surgical emergency The abscess usually lies posterior to the cord, except when it is secondary to disease of the vertebral bodies

Staphylococci of various types are the bacteria most commonly

* *Sulfathiazole powder* if placed on the surface of the brain has been shown recently to carry the hazard of inducing convulsions For cortical application only *sulfanilamide powder* should be used

responsible, but pneumococci, streptococci, and Eberthella typhi have been causative organisms. The epidural abscess may be part of a staphylococcic type of septicemia or it may be the only metastatic process from a primary staphylococcic lesion situated elsewhere, such as a furuncle or cellulitis, osteomyelitis of the vertebrae or sacrum, or inner extension through the vertebral foramina by an inflammatory process lying external to the spinal canal, such as a decubital ulcer of the sacrum. Posteriorly situated abscesses tend to spread up and down the extent of the epidural space, whereas anteriorly situated abscesses tend to localize and spread into the subarachnoid space.

Symptoms

The symptoms in this disease at first are those characterizing the presence of systemic infection, such as fever malaise, and leukocytosis. When the epidural abscess is the chief lesion, there is seldom an increase of more than 2° or 3° in body temperature, and the leukocyte count is likely to exceed 15 000 The first symptom to draw attention to the spinal region as the site of an infection is pain in the back. This pain may be exaggerated by coughing, sneezing, jugular compression, or movement of the spinal column. Spasm of the erector spinae muscles causes a striking rigidity of the neck in highly situated lesions, so that meningitis may be suspected. Kernig's sign can be elicited and tenderness over the spinal column in the region of the abscess may be marked. Radicular pains in the region of the abscess are common. Hyperesthesia, paresthesia, and numbness may be present in the zone of the involved nerve roots. The preceding prodromal symptoms may be present for some time before the serious manifestations of this disease occur or they may occur within the first few days of illness. The resulting compression type of myelitis of the spinal cord produces rapidly progressive signs of a transverse lesion situated below the level of the lesion. Localization is then somewhat simplified by the more definite sensory level. If the lesion is in the lower lumbosacral region, flaccid paralysis may develop in one extremity, with only weakness in the other If the lesion is situated in the cervical or thoracic region of the spinal column, partial or complete block may be demonstrated before definite signs of compression of the cord appear It should be borne in mind, however that in the performance of lumbar puncture removal of a small quantity of fluid may produce immediate paraplegia. If the abscess is situated in the lumbar region, lumbar puncture should not be carried out, for if it is, the abscess might be penetrated, with resultant contamination of the subarachnoid space. If the diagnosis is not suspected and lumbar puncture is

done, the escape of a few drops of pus is diagnostic of the true condition

Treatment

Surgical intervention is indicated as soon as the diagnosis is suspected Laminectomy should be performed at the site indicated by neurologic localization Three or four laminae should be removed If the abscess is too extensive it may be necessary to do double laminectomy, which should be spaced so that adequate drainage can be obtained Dakin tubes or small rubber catheters should be run up and down in the epidural space to the top and bottom of the cavity of the abscess Pus, which has extended from between the laminae, may be encountered in the muscles of the back When the laminae are removed, the epidural fat is seen to be hard and red and to bleed easily When the attempt is made to strip the fat from the dura, the cavity of the abscess is opened and thick pus under pressure escapes. The wound should be left open and packed sufficiently to control the bleeding The drains, of course, should be left in position until drainage has practically ceased

Accessory measures for the treatment of staphylococcic infections (and particularly staphylococcic septicemia), such as staphylococcic antitoxin, the transfusion of blood, administration of sulfathiazole, and supportive measures in general, should be employed Doses of staphylococcic antitoxin and sulfathiazole are discussed on page 188

APPENDIX

EXAMINATION FORMS FOR PERIPHERAL NERVE INJURIES

BYRON STOOKEY M.D., and JOHN SCARFF M.D

IF the final results of peripheral nerve injuries are to be evaluated, a standard form of examination is essential. The examination should include careful sensory charts and complete data concerning function of the muscles involved. The loss of function of individual muscles should be noted and not total movements. The following pages are intended to serve as models for examination forms applying to each wounded person who has undergone peripheral nerve injury (Figs. 68 to 70 inclusive and Charts 1 to 6 inclusive)

PERIPHERAL NERVE EXAMINATION

Name Grade Ward

LOCAL EXAMINATION OF SITE OF INJURY.—Indicate on attached diagram, wound of entrance, exit and position of scar. Note degree of scar features discernible on palpation of nerve, presence of neuroma, involvement of tendons by scar associated bony injuries, callus, presence or absence of infection and its extent.

MOTOR EXAMINATION.—Enumerate each individual muscle the action of which is lost or impaired. Do not indicate total movement but the action of each individual muscle. Check on attached chart each muscle involved. Beware of trick movements and effect of gravity on weak movements.

Fig. 68, a.

PASSIVE MOVEMENTS —Note limitations due to periarticular contractures, fixation of tendons in scar, bony and joint injuries

MUSCLE STATUS —Note atrophy, tone, fibrillary twitchings, direct myotatic irritability, tenderness, shortening of opposing muscles

TENDON REFLEXES

Fig 68, *b*

Peripheral Nerve Examination

Name Grade Ward

Electrical Examination.—Summary See chart.

Sensory Examination.—Complete charts. Tactile pain, temperature (moderate degrees, extreme degrees) Deep sensibility: vibratory muscle, joint and tendon sense.

Involvement of Sympathetic Fibers.—Vasomotor surface temperature, sweating, pilomotor

Fig. 69 a.

TROPHIC DISTURBANCES —Skin, texture, color, terminal pads, nails, bones, traumatic sores

ASSOCIATED INJURIES IN THE EXTREMITY —Bone, tendon, main blood vessels

REMARKS

Fig 69, *b*

Peripheral Nerve Examination

Muscle Innervation

Name Grade Ward

Suprascapular Nerve

Shoulder girdle
- Supraspinatus
- Infraspinatus

Long Thoracic Nerve

Shoulder girdle
- Serratus anterior

Axillary Nerve

Shoulder girdle
- Teres minor
- Deltoid

Musculocutaneous Nerve

Arm
- Biceps brachii
- Coracobrachialis

Median Nerve

Forearm—Via independent branches of the median nerve
- Pronator teres
- Flexor carpi radialis
- Palmaris longus
- Flexor digitorum sublimis
- Flexor digitorum profundus
  - Via volar interosseus nerve
- Flexor pollicis longus
- Flexor digitorum profundus—lateral half
- Pronator quadratus

Hand
- Abductor pollicis brevis
- Opponens pollicis
- Flexor pollicis brevis

Ulnar Nerve

Forearm
- Flexor carpi ulnaris
- Flexor digitorum profundus—medial half

Hand
- Flexor digiti quinti brevis
- Abductor digiti quinti
- Opponens digiti quinti
- Interossei
- Lumbricales—3rd and 4th
- Adductor pollicis—oblique and transverse parts
- Interosseus primus volaris—deep part of flexor pollicis brevis

Radial Nerve

Arm—Medial to humerus—upper third
- Triceps—long, medial, and lateral heads
  - Posterior to humerus—middle third
- Triceps—long, medial and lateral heads
- Anconeus
  - Lateral to humerus—lower third
- Brachioradialis
- Extensor carpi radialis
- Brachialis—small branch, occasionally

Forearm—Via deep ramus of radial nerve
- Extensor carpi radialis brevis
- Supinator longus
- Extensor digitorum communis
- Extensor digiti quinti proprius
- Extensor carpi ulnaris
- Abductor pollicis longus
- Extensor pollicis longus
- Extensor pollicis brevis
- Extensor indicis proprius

Fig. 70 a.

TROPHIC DISTURBANCES —Skin, texture, color, traumatic sores

ASSOCIATED INJURIES IN THE EXTREMITY —*Bone, tendon,* r

REMARKS

Fig 69, *b*

Peripheral Nerve Examination

Muscle Innervation

Name Grade Ward

Suprascapular Nerve

Shoulder girdle
- Supraspinatus
- Infraspinatus

Long Thoracic Nerve

Shoulder girdle
- Serratus anterior

Axillary Nerve

Shoulder girdle
- Teres minor
- Deltoid

Musculocutaneous Nerve

Arm
- Biceps brachii
- Coracobrachialis

Median Nerve

Forearm—Via independent branches of the median nerve
- Pronator teres
- Flexor carpi radialis
- Palmaris longus
- Flexor digitorum sublimis
- Flexor digitorum profundus
  - Via volar interosseus nerve
- Flexor pollicis longus
- Flexor digitorum profundus—lateral half
- Pronator quadratus

Hand
- Abductor pollicis brevis
- Opponens pollicis
- Flexor pollicis brevis

Ulnar Nerve

Forearm
- Flexor carpi ulnaris
- Flexor digitorum profundus—medial half

Hand
- Flexor digiti quinti brevis
- Abductor digiti quinti
- Opponens digiti quinti
- Interossei
- Lumbricales—3rd and 4th
- Adductor pollicis—oblique and transverse parts
- Interosseus primus volaris—deep part of flexor pollicis brevis

Radial Nerve

Arm—Medial to humerus—upper third
- Triceps—long, medial and lateral heads
  - Posterior to humerus—middle third
- Triceps—long, medial and lateral heads
- Anconeus
  - Lateral to humerus—lower third
- Brachioradialis
- Extensor carpi radialis
- Brachialis—small branch, occasionally

Forearm—Via deep ramus of radial nerve
- Extensor carpi radialis brevis
- Supinator longus
- Extensor digitorum communis
- Extensor digiti quinti proprius
- Extensor carpi ulnaris
- Abductor pollicis longus
- Extensor pollicis longus
- Extensor pollicis brevis
- Extensor indicis proprius

Fig. 70 a.

FEMORAL NERVE
- Pectineus
- Sartorius
- Quadriceps femoris (several branches)

OBTURATOR NERVE
- *Anterior muscle group*
  - Adductor longus
  - Gracilis
  - Adductor brevis (usually)
  - Pectineus (occasionally)
- *Posterior muscle group*
  - Obturator externus
  - Adductor magnus
  - Adductor brevis (occasionally)

SCIATIC NERVE TIBIAL DIVISION
- *Thigh*—nerve to hamstrings
  - Semimembranosus
  - Semitendinosus
- *Popliteal space*—tibial nerve
  - Gastrocnemius
  - Plantaris
  - Popliteus
  - Soleus
- *Leg*—tibial nerve
  - Tibialis posterior
  - Flexor digitorum longus
  - Flexor hallucis longus
- *Foot*—tibial nerve
  - Plantar muscles of the foot

SCIATIC NERVE PERONEAL DIVISION
- *Thigh*—Nerve to biceps femoris
  - Biceps femoris—short head
- *Leg*—deep peroneal nerve
  - Tibialis anterior
  - Extensor hallucis longus
  - Extensor digitorum longus
  - Peroneus tertius
- *Leg*—superficial peroneal nerve
  - Peroneus longus
  - Peroneus brevis
- *Foot*—terminal branches, deep peroneal nerve
  - Extensor digitorum brevis

Fig 70, *b*

Peripheral Nerve Examination

Name Grade Ward

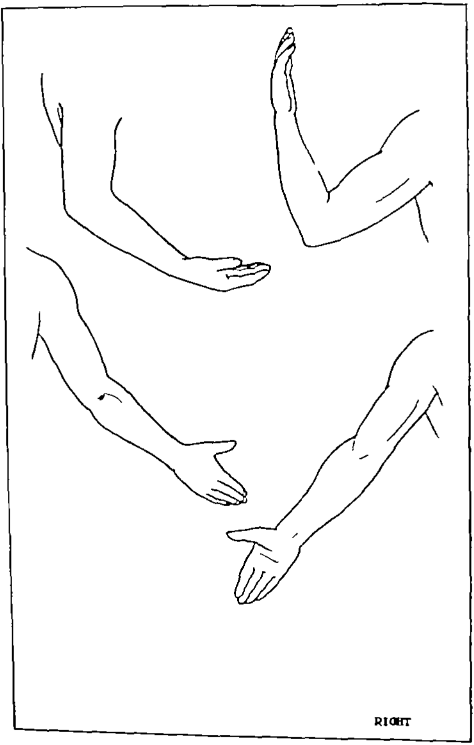

Chart 1.

FEMORAL NERVE
- Pectineus
- Sartorius
- Quadriceps femoris (several branches)

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Fig 70, *b*

Peripheral Nerve Examination

Name Grade Ward

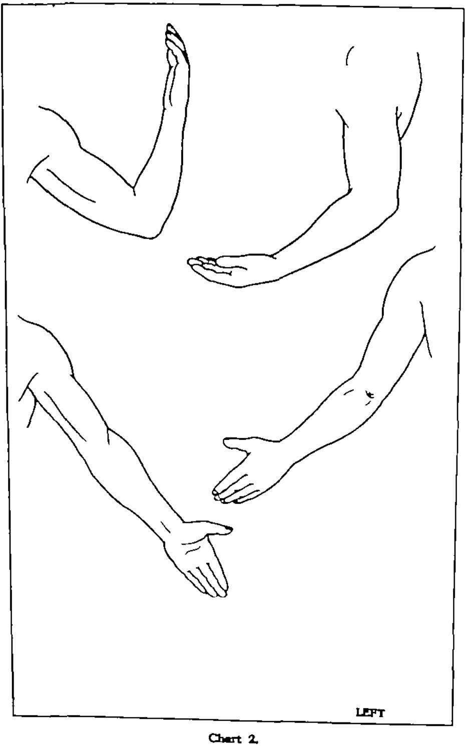

Chart 2.

APPENDIX

REMARKS

Peripheral Nerve Examination

Name Grade Ward

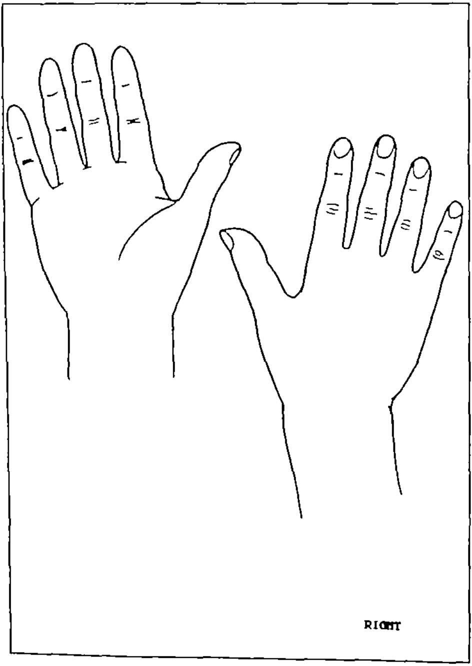

Chart 3.

REMARKS

Peripheral Nerve Examination

Name Grade Ward

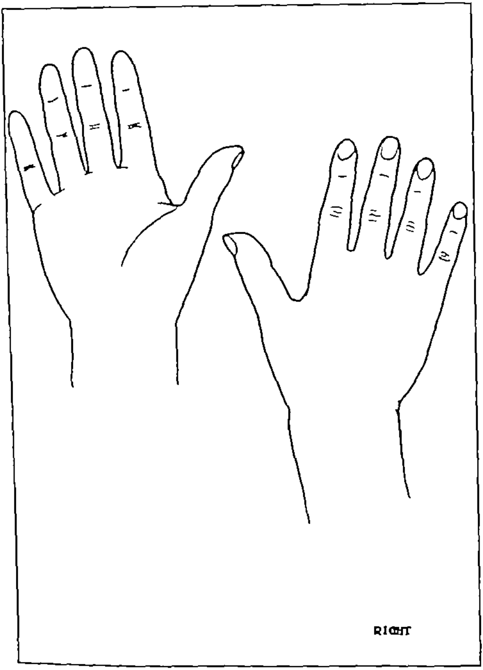

Chart 3.

REMARKS

Peripheral Nerve Examination

Name Grade Ward

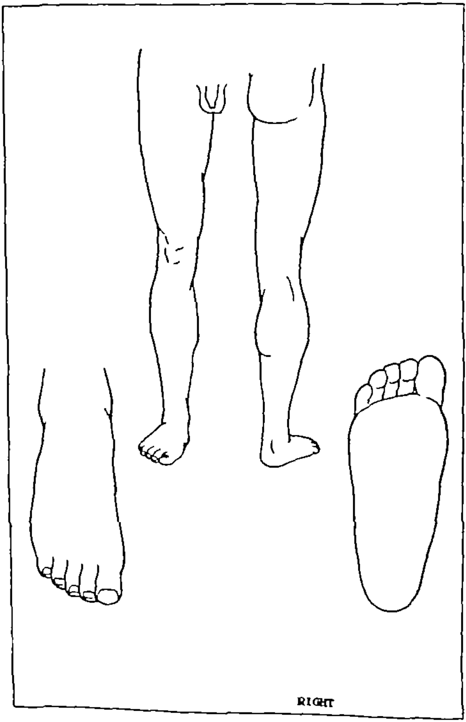

Chart 5.

REMARKS

Peripheral Nerve Examination

Name Grade Ward

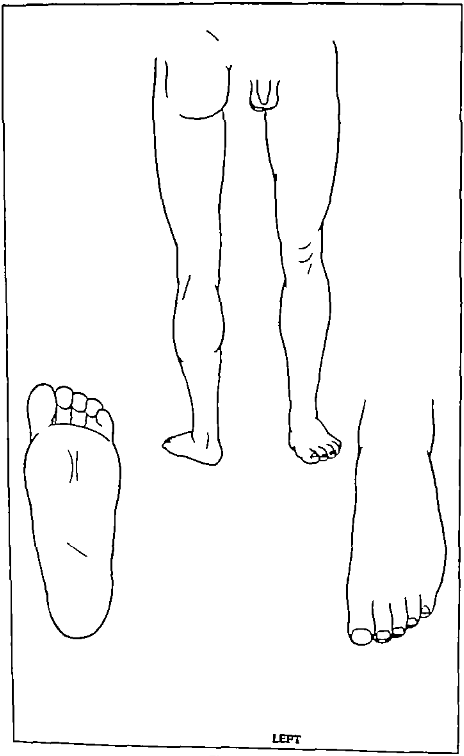

Chart 6.

REMARKS

THORACIC SURGERY

REMARKS

THORACIC SURGERY

THORACIC SURGERY

Prepared and Edited by the Subcommittee on Thoracic Surgery of the Committee on Surgery of the Division of Medical Sciences of the National Research Council

EVARTS A. GRAHAM, *Chairman*

ISAAC A. BIGGER EDWARD D CHURCHILL

LEO ELOESSER

PREFACE

THE immediate mortality from thoracic wounds inflicted by high explosive missiles is very great. Examination of the dead on the battlefield has shown that approximately 33 per cent died of thoracic injuries. The mortality at dressing stations has been cited at 25 to 30 per cent, and in ambulances, 20 to 25 per cent. The mortality rate resulting from thoracic injuries in military hospitals depends on whether the speed of evacuation and the distance of transportation permit an appreciable number of the seriously wounded to live long enough to reach the hospital.

An attempt to reduce the mortality rate among men wounded in the chest must be made within the combat zone. This does not mean indiscriminate application of heroic measures in advanced surgical stations. In fact, the adoption of such a policy would most likely increase the mortality rate, as many of the seriously wounded will die despite any form of treatment, while hasty intervention will in itself prove fatal to men who might survive under conservative measures. What is needed is more accurate appraisal of the individual patient, with prompt first-aid control of certain complications of thoracic wounds. Following proper first-aid treatment, definitive measures are carried out with due regard to certain special aspects of thoracic wounds that set them apart from wounds of the head, abdomen, or extremities.

The subject matter of this manual has been rigorously limited to these special problems offered by wounds and injuries of the thorax. The general principles of military surgery and the operative management of traumatic injuries, instruction regarding débridement, chemotherapy the treatment of shock and hemorrhage, the administration of tetanus antitoxin and toxoid, and similar matters that are common to all traumatic injuries have purposely been omitted.

Limitation of the subject matter to practical diagnosis and applied therapy has led to the exclusion of certain other topics on which the skilled management of thoracic injuries must be based. Standard reference works can be consulted for more complete exposition of the physiopathology of the cardiorespiratory mechanism, the principles underlying differential pressure anesthesia, thoracic roentgenology

endoscopy, and particularly the advances of the past decade in the field of nontraumatic surgery of the chest.

The subject matter has been divided into four parts Chapter I deals with the adaptation of general surgical principles to the special problems of thoracic injuries Chapter II is a synopsis of treatment and disposition, designed as a reference manual for the personnel of advanced surgical stations Chapter III presents in more detail the diagnosis, first aid, and definitive treatment of thoracic injuries and complicating conditions Chapter IV contains a description of technical procedures mentioned in the preceding sections

Even a hasty glance will assure the reader that this is not a textbook of thoracic surgery. It is designed as a reference manual for medical officers in the field, caring for wounded men under the exigencies of enemy action Corrective operations and more extensive procedures to be undertaken by competent surgeons in hospitals removed from the combat zone are not considered

SUBCOMMITTEE ON THORACIC SURGERY
Committee on Surgery
Division of Medical Sciences
National Research Council

CONTENTS

THORACIC SURGERY

CHAPTER I

GENERAL PRINCIPLES PERTAINING TO THORACIC INJURIES

FIRST AID MEASURES

THE first-aid management of thoracic injuries is concerned with (1) the arrest of hemorrhage from the thoracic wall, (2) physical correction of disturbances of cardiorespiratory physiology, and (3) prevention of infection. Arrest of hemorrhage is carried out according to established principles of general surgery and requires little comment; management of disturbances of the function of the heart and lungs requires a basic understanding of the dynamics of the chest.

A defect of the thoracic wall results in a "sucking" wound that requires immediate airtight closure. Air accumulating under pressure in the pleural cavity often forcing its way into tissues as mediastinal or subcutaneous emphysema, must be afforded a vent. Extensive fractures of the ribs or sternum, or defects of three ribs or more following débridement of a wound, result in paradoxical motion of the mobile thoracic wall and demand stabilization by secure strapping or external fixation. Progressive hemorrhage into the pleural cavity from a lacerated lung is treated by aspiration and simultaneous replacement with air (artificial pneumothorax). Progressive hemorrhage into the pericardium from a wound of the heart results in cardiac tamponade that can be relieved by aspiration with a hollow needle. Aspiration may be repeated if necessary until the need of cardiorrhaphy is demonstrated and facilities are available for carrying out the operation.

SUBSEQUENT TREATMENT

Definitive surgical treatment for intrathoracic injuries is best carried out with the patient under intratracheal anesthesia to provide differential pressure. Proper débridement of a thoracic wound may include removal from the lung of fragments of high explosive missiles, resection of devitalized or bleeding pulmonary tissue, hemo-

but, as a rule, a conscious patient does not tolerate pressure sufficient to inflate the lung.

Local anesthesia may be employed to supplement general anesthesia in the course of operations on the thoracic wall. Infiltration of the hilum of the lung may block disturbing vagal reflexes. Motion of the diaphragm can be stopped by direct injection of the phrenic nerve or more simply by crushing it with a hemostat.

Associated Injuries

Abdominothoracic injuries are discussed under a separate heading.

The gravity of associated head injuries is increased by the elevation of venous pressure that may attend injury to the thorax.

In general, correction of the cardiorespiratory disturbance incident to a wound of the thorax must precede the definitive surgical treatment of associated injuries.

Hemorrhage and Shock

A man can bleed to death into his pleural cavity without serious disturbance of respiration being caused by encroachment on pulmonary volume. The mechanical effects of hemothorax are delayed because they are produced by a traumatic effusion superimposed on the initial collection of blood. Bleeding from even extensive lacerations of the lung tends to stop spontaneously partly because of the low head of pressure in the pulmonary circulation and partly because of collapse of the organ from the attendant hemothorax or pneumothorax.

In the presence of a thoracic injury that reduces pulmonary volume, shock accompanied by hemoconcentration should be treated by infusion of blood substitutes rather than transfusion of whole blood. The increased viscosity attending hemoconcentration interferes with oxygenation in the pulmonary circuit and possibly adds to the burden of the right side of the heart.

In general it is advisable to keep a patient with an injured lung slightly dehydrated rather than to invite pulmonary edema by the too liberal use of intravenous infusions. Blood replacement therapy is to be delayed as long as possible in the presence of continuing intrapulmonary hemorrhage.

A small (200 to 300 cc.) hemorrhage into the pericardium may produce cardiac tamponade. Repeated transfusions will have only temporary value until the tamponade is released.

static suture of lacerated lung, airtight closure of divided bronchi, removal of foreign material and devitalized tissue from the pleural cavity and thoracic wall, and reexpansion of normal pulmonary tissue followed by airtight closure of the thoracic wall

Empyema is to be prevented if possible; if it occurs, proper drainage is instituted and a chronic phase prevented

Delayed removal of certain foreign bodies is advisable

Evacuation and Transportation

The risks of prolonged transportation and of early operation should be carefully considered and weighed against each other It should be remembered that many men with apparently desperate injuries recover under conservative treatment and that early, open thoracotomy by an inexperienced surgical team is extremely hazardous Early intervention is urgently indicated in the presence of progressive bleeding, open pneumothorax, pressure pneumothorax or cardiac tamponade Early control of infection is less imperative and should not impel an inadequately equipped medical officer to operate Difficulties of evacuation may force intervention which, when transportation is at hand, may be put off until a later and better equipped installation is reached

Transportation by airplane is to be avoided if anoxemia or large, closed pneumothorax exists If oxygen is available during transportation, these contraindications may be subject to modification

Anesthesia

Differential pressure anesthesia is advisable for major operations in which the pleural cavity is widely opened It is best carried out by tracheal intubation, a method that at the same time provides for aspiration of blood and mucus from the trachea and bronchi during operation Differential pressure may also be obtained by a tightly fitting face mask.

Anesthetic agents that may be combined with a high percentage of oxygen (ether, cyclopropane) are preferable to agents the use of which is attended by anoxia (nitrous oxide) Vasoconstrictor drugs (such as epinephrine) should not be used when general anesthesia has been effected by cyclopropane, chloroform, ethyl chloride or perhaps tribromethyl alcohol in amylene hydrate (avertin) because of the danger of ventricular fibrillation

Regional block or infiltration anesthesia is suitable for operation on the thoracic wall Local anesthesia or spinal anesthesia may be combined with the administration of oxygen under slight pressure

use is contraindicated. A dangerous elevation of carbon dioxide tension may already exist.

The use of *tobacco* may be harmful through the coughing it incites. If this is negligible, smoking in moderation may be permitted during convalescence.

Drainage of the Pleural Cavity

Pleural drainage is used for (1) prevention or correction of infection and (2) prevention or correction of mechanical embarrassment of respiration.

Open drainage that allows free entrance of air into the pleural cavity at the time of operation or subsequently is employed only for encapsulated collections of pus, with firm adhesions between the rest of the lung and the thoracic wall. It has no place in the early treatment of thoracic injuries.

Closed drainage prevents entrance of air into the chest but allows escape of fluid and air It is established by an intercostal tube (usually trocar and catheter) *Constant closed drainage* can be provided by attaching a flap valve (condom or finger cot) to the end of the catheter or better by connecting the catheter to a longer tube (sterilized) the end of which is immersed in water A trap bottle for collection of the exudate is conveniently placed between the chest and the water-seal valve. The suction of the chest will draw in the water unless this trap is provided or unless the water valve is placed at least 3 feet (91 cm.) below the point where the tube enters the chest. *Intermittent closed drainage* is accomplished by keeping a clamp on the catheter except when an aspirating syringe is being used. *Constant closed drainage with suction* or *closed drainage with intermittent irrigation and suction* may be applicable in specialized situations but for practical reasons can be carried out only in well organized hospitals.

Constant closed drainage *must* be employed for continuing pressure pneumothorax and (rarely) for rapidly increasing exudates, resulting from infection, that cannot be adequately removed by repeated aspiration with the needle. Closed drainage for forty-eight hours is advisable following extensive débridement of the lung and pleural cavity as evacuation of the serosanguineous exudate minimizes the hazards of infection and promotes reexpansion of residual lung. It also protects against immediate pressure pneumothorax that results from leakage of air from the bronchi and it reveals postoperative hemorrhage. A fulminating infection of the pleural cavity that may appear within forty-eight hours becomes recognizable by the

Pleural Shock and Air Embolism

While temporary fall in blood pressure and apnea may attend manipulation of the pleura or lung, particularly in the hilar region, so-called pleural shock is usually a result of air embolism A small amount of air entering a pulmonary vein may be carried through the left side of the heart, to lodge in a cerebral artery Death may occur abruptly If the man survives, convulsions or transient hemiplegia may be manifest Air must never be introduced through a needle entering the thorax unless it is certain that the point of the needle does not communicate with a radicle of a pulmonary vein. In surgical procedures involving the lung the patient's head is placed lower than his hips to lessen the possibility of cerebral air embolism

The Use of Drugs

Patients with severe mechanical disturbances of respiration suffer from asphyxia, for which *oxygen therapy* is instituted at the earliest moment it is available

Morphine may make respiratory movements more effective by diminishing pain but care should be taken not to abolish the cough reflex or to induce respiratory depression

Atropine is used by some thoracic surgeons in liberal dosage ($1/100$ grain [0 0006 gm] repeated in forty-five minutes) as preoperative medication to lessen vagal reflexes and diminish secretion of mucus. It is used in even larger doses for cardiac tamponade On the other hand, it has a tendency to increase the viscosity of the bronchial secretions and to make it more difficult to clear the tracheobronchial tree by coughing

Use of *barbiturates* is contraindicated in conditions associated with low concentration of oxygen or high concentration of carbon dioxide in the blood The use of barbiturates for maintenance of anesthesia is also contraindicated if differential pressure anesthesia is to be employed

The cough reflex is not to be depressed by *codeine* or cough mixtures when it is essential for the patient to evacuate pus by coughing

Respiratory stimulants will rarely be required or be effective if used *Caffeine* or preferably 25 per cent solution of pyridine betacarboxylic acid diethylamide (the proprietary preparation *coramine*) is indicated for periodic respiration *Carbon dioxide* is to be used with caution as a respiratory stimulant when pulmonary ventilation is inadequate If it does not produce an immediate response its further

As is true of treatment for other wounds, chemotherapy is not a substitute for proper surgical methods.

Use of systemic chemotherapy as a routine is advisable in cases of injury of the chest to prevent pneumonia or pulmonary suppuration. This is particularly important if the wounded man has suffered from exposure or if respiratory infection is prevalent.

Chemotherapy may not prevent empyema but is of great value if it merely delays its appearance. Despite a high concentration of the drug in the blood, it may not penetrate large masses of blood clot in the pleural cavity or its action may be inhibited by the products of protein decomposition. Surgical evacuation of the clot, with local reapplication of the drug and its continued systemic use, may obviate drainage for hemothorax accompanied by infection of low grade.

Problems of Convalescence

Early ambulatory treatment aids reexpansion of a collapsed lung. Patients are instructed in deep breathing exercises designed to strengthen the muscles of respiration and to restore the symmetry of the thorax. Especial attention is directed to the prevention or correction of scoliosis. Free motion of the shoulder girdle is developed by exercises.

Hemoptysis late in convalescence may be attributable to pulmonary infarction, granulation tissue in a healing bronchus or bronchial fistula, foreign body in the lung or pleura, bronchiectasis or activation of latent pulmonary tuberculosis. Treatment is by rest until a proper diagnosis can be made.

Expectoration of pus after the healing of an external sinus usually indicates incomplete healing of an empyema cavity that communicates with a bronchus. The pus may also find origin in a residual pulmonary cavity or focus of bronchiectasis. It may be necessary to reestablish external drainage until complete appraisal of the situation can be made.

A sinus of the thoracic wall that persists longer than four to six weeks after removal of drainage tubes is usually indicative of a residual empyema cavity with a bottleneck type of drainage tract. A persistent sinus may also be caused by an infected foreign body. Osteomyelitis of ends of ribs is rare, but a fragment of rib from a compound, comminuted fracture, or a sequestrum from a rib denuded of its periosteum and left in an infected field, may be found in a persistent sinus.

A bronchopleural fistula usually heals as the empyema cavity

character of the drainage In the presence of established infection or bad contamination, with infection apparently inevitable, closed drainage is continued or later is converted into dependent, open drainage after the infected region has become encapsulated

Drainage is not employed for sterile hemothorax Collections of blood that cannot be evacuated with a needle can be removed with trocar and catheter used as means of thoracentesis Increasing hemothorax from continuing pulmonary hemorrhage is treated by aspiration of blood and simultaneous replacement with air

Drainage tubes are irrigated only to maintain their patency and for this purpose warm saline solution should be used Irrigation of the pleural cavity with chemical antiseptic substances is generally to be condemned, although the use of carefully prepared Dakin's solution (buffered 0 5 per cent solution of sodium hypochlorite) is favored by many after the pleural exudate is definitely purulent Irrigation is never to be employed when a fistula exists between lung and pleural space

Drainage tubes must be anchored securely to the external thoracic wall to avoid their retraction into the pleural cavity When a tube is draining a region of established infection it cannot safely be removed until the cavity it drains has become obliterated In empyema the progress of obliteration of the cavity can best be determined by actual measurement of the volume of the cavity from time to time The patient is placed so that the drainage opening is uppermost Known quantities of sterile saline solution are injected until it overflows The drainage tube is not removed permanently until the capacity of the cavity is 10 cc or less This method cannot be employed if a pleurobronchial fistula exists Iodized oil (lipiodol) is then used under roentgenoscopic guidance

Chemotherapy

Crystals of a sulfonamide may be used in the pleural cavity or the thoracic wall The rate of absorption from the pleural surface is approximately the same as that from the alimentary tract The total dosage, therefore, must be regulated accordingly, with appropriate correction if the drug has been employed prior to operation

Local application is followed by systemic maintenance of chemotherapy If drainage of the pleural space is employed a varying proportion of the drug applied locally will be evacuated with the effusion Observations of the concentration of the drug in the blood are necessary for precise control of dosage in the important immediate postoperative period

CHAPTER II

SYNOPSIS OF TREATMENT AND DISPOSITION OF THORACIC INJURIES

---

1 Tangential or Nonpenetrating (Pleural Cavity Not Entered) Wounds without Hemoptysis, Effusion, Hemorrhage, or Shock

(a) *First Aid* Dressing. Chemotherapy

(b) *Definitive Treatment.*

Gunshot wounds (bullet) Usually conservative. Wound excision (?)

Fragment of high explosive missile. Wound excision.

2 Tangential or Nonpenetrating Wounds with Hemoptysis

(a) *First Aid* Dressing. Chemotherapy Circular bandage. Morphine.

(b) *Definitive Treatment*

Gunshot wounds. Dressing or wound excision.

Fragment of high explosive missile. Wound excision.

If bleeding is severe or persistent, artificial pneumothorax. Careful observation to include X-ray of chest if hemoptysis persists or tuberculosis is suspected.

3 Tangential or Nonpenetrating Wounds with Simple, Not Compounded Rib Fracture (Single or Multiple)

(a) *First Aid.* Dressing. Chemotherapy Circular bandage. Morphine. Intercostal nerve block for severe pain.

(b) *Definitive Treatment.*

Gunshot wounds. Usually conservative. X ray Circular elastic bandage.

Fragment of high explosive missile Wound excision including careful search for foreign bodies. Circular elastic bandage. Careful observation for infection.

4 Compression Injuries with Traumatic Asphyxia or Cyanosis Involving the Head Neck, and Shoulder Girdle. Due to compression of the thoracic viscera as the re-

obliterates itself or is closed by plastic operations late in convalescence A bronchocutaneous fistula may persist indefinitely and operation for closure can be undertaken only late in convalescence, after complete appraisal of the condition of the surrounding lung and adjacent bronchial tree

Infection of a preexisting but asymptomatic bronchiectatic lesion may follow respiratory infection or the hardships of military service. Purulent sputum, hemoptysis and recurring pneumonitis are characteristic symptoms Surgical operation is undertaken only as a measure of rehabilitation in connection with discharge from active service.

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Fragment of high explosive missile Wound excision including careful search for foreign bodies. Circular elastic bandage. Careful observation for infection.

4 **Compression Injuries with Traumatic Asphyxia or Cyanosis Involving the Head Neck, and Shoulder Girdle.** Due to compression of the thoracic viscera as the re-

sult of cave-ins, falling buildings, or being crushed by, or between, moving vehicles Blood is expelled from the great veins and right auricle into the valveless jugular and subclavian veins The head, neck and shoulders are purple and ecchymotic, the eyes protrude, the tongue and lips are dusky and swollen There are multiple ecchymoses and petechiae, and there may be coma from intracranial hemorrhage or choked disk and blindness Recovery from coma may be protracted If the patient survives the first day he usually will recover spontaneously.

(a) *First Aid* Rest Chemotherapy. Respiratory stimulants

(b) *Definitive Treatment* Inhalation of oxygen for respiratory distress Respiratory stimulants Examine for associated injuries such as ruptured diaphragm or rupture of abdominal viscera

5. **Extensive Mobilization of the Thoracic Wall by Rib Fractures.** Very extensive unilateral rib fractures may produce serious respiratory embarrassment because of the paradoxical movement of the mobilized wall and shifting of the mediastinum In presence of extensive bilateral fractures, adequate expansion of the lung may be impossible. They occur on shipboard from gun recoil

(a) *First Aid* Morphine in moderate dosage The pain may be relieved by the injection of the corresponding intercostal nerves with 1 per cent procaine Circular adhesive strapping, particularly for unilateral injuries Immobilization by adhesive tape may also be tried for bilateral fractures but tape should be removed if it causes increased respiratory distress Rest. Oxygen Patients breathe better seated than recumbent

(b) *Definitive Treatment* Oxygen In some unilateral and most bilateral injuries the thoracic wall should be stabilized and elevated by perichondrial wire sutures or towel clips attached to the third and fifth costal cartilages The wires or towel clips are then connected with a weight by overhead pulley (Balkan frame), or attached to a plaster jacket Continue immobilization until chest is stable (at least three weeks)

6 **Massive Atelectasis.** Massive atelectasis or collapse may involve the injured, or more rarely the contralateral, lung,

following blunt or penetrating thoracic injuries with or without rib fracture. It produces dyspnea, fall in blood pressure, sometimes cyanosis. Dulness is associated with distant or absent breath sounds (often over the whole hemithorax, whereas in the presence of fluid characteristic signs are found over the dependent parts of the chest while the upper portion is resonant) Movement of the hemithorax is restricted, the diaphragm is elevated and there is displacement of the trachea, the heart (apex beat) and other mediastinal structures *toward* the affected side. Atelectasis is due to causes which prevent movement of air in all or a part of one lung, such as splinting of the thoracic wall and diaphragm from pain, aspiration of blood, mucus, or a foreign body or compression of one of the main bronchi.

(a) *First Aid* Morphine, only in small amounts, if at all. Place patient on uninjured side force cough and deep breathing. Chemotherapy

(b) *Definitive Treatment.* If maneuvers just suggested do not clear the lung, bronchoscopy or aspiration by means of an intratracheal catheter may be indicated.

7 **Penetrating Injuries without Serious Hemorrhage or Shock**

(a) *First Aid* Dressing. Circular bandage Morphine. Chemotherapy

(b) *Definitive Treatment.*

Gunshot wound X ray Treatment usually conservative, occasionally wound excision.

Fragment of high explosive missile X-ray Wound excision. Thoracotomy and removal of foreign bodies. Especially careful search for organic foreign bodies, such as bits of clothing. Careful observation for development of infection (empyema)

8. (A) **Penetrating Injuries with Shock and Hemothorax from Intercostal Vessels.** To be suspected if signs of hemothorax are present without expectoration of blood.

(a) *First Aid* Treat for shock. Administer whole blood or plasma. In case of open wounds apply direct ligature or pericostal suture to bleeding artery Morphine. Chemotherapy Place patient on injured side. If there is continued bleeding (evi-

denced by increasing hemothorax and persistent shock), the wound should be excised and the bleeding controlled if at all possible

(*b*) *Definitive Treatment* Excision of wound and ligature of artery, with rib resection if necessary Close chest without drainage Observe for empyema Aspirate chest if massive effusion occurs

(B) Penetrating Injuries with Shock and Hemorrhage from Injuries to Internal Mammary Artery. Exsanguination may take place rapidly, in two or three hours or even less To be suspected if course of missile traverses site of artery 1 cm lateral to sternal border, if bright red blood escapes from wound, and if signs of hemothorax are present without hemoptysis

(*a*) *First Aid* Treat for shock Administer blood or plasma Chemotherapy Incise and ligate both ends of artery if circumstances permit Place man on injured side

(*b*) *Definitive Treatment* Expose and ligate both ends of artery Remove blood by suction Close thoracic wall without drainage Observe for empyema Aspirate chest if massive effusion occurs

(C) Penetrating Injuries with Shock and Hemorrhage from Laceration of Lung. Laceration of the lung is to be suspected if signs of hemothorax are present and the wounded man expectorates blood This sign is not wholly reliable, for bloody expectoration may be absent if the periphery of the lung is torn, or again, blood may be expectorated from a contusion of the lung without laceration

(*a*) *First Aid* Treat for shock. Administer blood or plasma Dressing Morphine Chemotherapy Place man on injured side or sitting up

(*b*) *Definitive Treatment* X-ray Small, penetrating wounds (bullet) not admitting air may be treated conservatively More extensive wounds, especially those made by irregular fragments, are treated by débridement of the skin and muscles, with closure, or by the application of a gauze dressing without closure of the skin By placing

the man in a position so that a small, penetrating wound is dependent, evacuation of blood from the pleural cavity may take place spontaneously Small effusions are treated conservatively

Effusions extending above the sixth rib posteriorly are treated by aspiration and simultaneous replacement with air Aspiration may be done with a needle of large caliber or by the trocar cannula-catheter method. The catheter is usually removed as soon as the blood has been evacuated but it may be left in for a few hours if there are special indications for so doing. Infection will follow if the catheter is allowed to remain for too long a period.

If bleeding from the lung into the pleural cavity continues, aspiration and replacement with air (artificial pneumothorax) in sufficient amount actually to compress the lung, is indicated. If bleeding continues despite compression of the wounded lung, thoracotomy becomes mandatory

Wounds caused by fragments of high explosive missiles require careful débridement of the thoracic wall and removal of foreign material from the pleural cavity and substance of the lung. The lacerated portion of the lung may be resected or the damaged lung may be brought into the wound and secured by sutures, closing the thoracic wall around a gauze pack.

Airtight closure is essential. This may be by primary closure or if the security of the pulmonary suture (bronchial air leak) hemostasis, and asepsis seem doubtful, drainage by water-seal catheter may be instituted. If empyema does not develop the catheter may be removed when the postoperative effusion has been evacuated, usually at the end of forty-eight hours. Leaving it longer invites infection. Observe for empyema. Aspirate residual or recurrent collections of fluid.

Choice of station at which definitive surgical treatment of thoracic injuries with severe laceration of the lung is instituted, is governed by military exigencies and the equipment and assistance

available Decision between operation and conservative treatment must be shaped by the facilities at hand and the competence of the surgical team Remember that infection of the pleural cavity may be dealt with later, while open operation under unfavorable circumstances may lead to disaster. Necessity for prompt evacuation need not be understood to contraindicate treatment at advanced stations, for men wounded in the manner considered here often stand transportation better in the first twenty-four hours after operation than they do a few days later

(D) **Penetrating Injuries with Shock and Hemothorax from Wounds of Heart with Communication between Pericardial Cavity and Pleural Cavity.** Massive intrapleural hemorrhage. Churning sound over heart. Men rarely survive to reach dressing station In case of survival

(*a*) *First Aid* Morphine and atropine Treat for shock. Administer blood or plasma

(*b*) *Definitive Treatment*

Bullet wound Aspiration of hemothorax. If bleeding continues or recurs, transpleural exposure, cardiorrhaphy

Fragment of high explosive missile Indications for cardiorrhaphy same as above Wound excision, removal of foreign bodies, cardiorrhaphy Observe for infection of pleura and pericardium Aspirate residual or recurrent collections of fluid in either cavity If purulent fluid is obtained from the pericardial cavity, immediate open drainage is indicated

(E) **Penetrating Injuries with Wounds of Heart and Cardiac Tamponade.** Circulatory collapse Distended external jugular veins Muffled heart sounds (quiet heart) Immobile cardiac shadow on fluoroscopy.

(*a*) *First Aid* Morphine, grain $\frac{1}{4}$ (0 016 gm) plus atropine, grain $\frac{1}{60}$ (0 00132 gm)

Bullet wound or *fragment of high explosive missile* Aspiration of blood from pericardium by costoxiphoid route

(*b*) *Definitive Treatment.* If tamponade recurs or persists, aspirate. If it again recurs, extrapleural exposure and cardiorrhaphy Observe for empyema of pericardium and pleura. Prompt open drainage for empyema of the pericardium.

9 **Penetrating Injuries with Loss of Substance of Thoracic Wall. (Sucking Pneumothorax)**

(a) *First Aid* Morphine. Chemotherapy Immediate airtight closure by suture, strapping or bandage. Treat for shock. Keep patient on injured side. Oxygen.

(*b*) *Definitive Treatment.* Débridement to include excision of wound as well as removal of foreign bodies. Air tight closure by use of diaphragm, muscles of thoracic wall, suture of lung to thoracic wall, or skin flap when necessary Intercostal closed drainage as indicated. Observe for empyema. Aspirate for large effusion.

10 **Penetrating Injuries or Other Injuries with Pressure Pneumothorax** Labored respiration, increasing dyspnea together with tympanitic hyperresonance, absence of breath sounds on the affected side, and deviation of the trachea, apex beat and mediastinum toward the unaffected side.

(a) *First Aid.* Morphine Chemotherapy Puncture in the second intercostal space anteriorly with a large bore (15 gauge) short (2 inch or 5 cm.) needle. Needle should be left in place only if air continues to escape under pressure. First-aid dressing. Place patient on injured side. Beware of evacuation by airplane.

(*b*) *Definitive Treatment. Gunshot wound* If air continues to escape under pressure, replace needle with constant closed trocar-cannula-catheter drainage.

Fragment of high explosive missile X-ray Wound excision. Thoracotomy foreign body removal, suture of perforation in lung If perforation is small, airtight closure. If associated with extensive laceration of lung, the injured segment of lung may be resected or sutured to the wound margins and surrounded by gauze pack. Intercostal closed drainage. Observe for empyema and reexpansion of lung.

11. Penetrating Wounds of Trachea, Primary Bronchi, or Esophagus with Mediastinal Emphysema. Recognized by deep emphysema in neck, labored respiration, dyspnea, and engorgement of veins of neck and upper extremities Mediastinal emphysema may be accompanied by pressure pneumothorax, which should be treated as described in the preceding section

(a) *First Aid* Morphine Chemotherapy Suprasternal incision to allow escape of air if warranted by dyspnea. Nothing by mouth if wound of esophagus is suspected

(b) *Definitive Treatment* If emphysema and dyspnea are progressive, suprasternal incision to provide for escape of air from deep planes of neck. If condition not relieved, low collar incision with severance of muscle attachments if necessary for adequate exposure Separation of loose cellular mediastinal tissue to level of wound in air passage Loose vaseline or plain gauze pack around a soft rubber tube down to perforation in trachea or bronchus or, if patient's condition permits, major thoracotomy and repair of perforation in airway. Latter procedure should be undertaken only when proper facilities are available and when shock has been completely controlled. If wound of esophagus is demonstrated by X-ray or otherwise, repair is imperative as soon as conditions permit. Feed with Levine tube and parenterally Observe for mediastinitis (Chills and fever, pain, discomfort on swallowing X-ray—widening of mediastinal shadow)

Drain high mediastinal abscess by cervical route. For descending suppuration, low posterior mediastinotomy is indicated.

12 Penetrating Injuries with Subcutaneous ("Surgical") Emphysema. Subcutaneous emphysema is distressing but rarely dangerous or fatal. It almost always recedes spontaneously Look for pressure pneumothorax, or mediastinal emphysema, and direct treatment to those complications Differentiate from gas bacillus infections, which are accompanied by fever and evidence of severe toxemia

(a) *First Aid* Morphine Chemotherapy Circular bandage with elastic compression dressing at site of wound.

(b) *Definitive Treatment* Morphine. Compression at site of injury by elastic compression dressing or sandbag weighing 1 to 2 pounds (about 0.5 to 1 kg.) *Rarely,* if the subcutaneous emphysema is progressive, excision of wound down to site of perforation of thorax. Repair Observe for empyema or phlegmon of thoracic wall.

13 **Perforating Injuries (Those with Wounds of Entrance and Exit)** *Gunshot wounds.* As under penetrating injuries except that removal of foreign bodies is ordinarily unnecessary

Fragment of high explosive missile. X ray for retained particles of missile. Removal of irregular fragments.

14 **Pleuro-abdominal Wounds (Transdiaphragmatic)**

(a) *First Aid.* Morphine. Chemotherapy Close sucking thoracic wound immediately Treat man for shock. Administer blood or plasma. Transfer to surgical hospital as soon as possible.

(b) *Definitive Treatment* Treat for shock. Examine for abdominal injuries. Wound excision. Suture diaphragm and crush phrenic nerve if diaphragmatic injury is extensive Control pulmonary hemorrhage by suture or resection, and close chest tightly using diaphragm if necessary Treat intra-abdominal injuries either via thoracotomy and transdiaphragmatic laparotomy or via direct laparotomy For *right-sided injuries* with laceration of liver pack subdiaphragmatic space and drain through posterior or lateral incision with rib resection (below diaphragm) if necessary *Left-sided injuries* involving the stomach or spleen do not require abdominal drainage. They are readily accessible through the diaphragm. After repairing injuries to abdominal viscera the diaphragm is repaired. The chest may be drained by dependent intercostal catheter (water-seal drainage) if it is grossly contaminated. Keep abdomen and pleural cavity separate by diaphragmatic repair

Observe for empyema and intra-abdominal complications, especially subdiaphragmatic abscess.

15. Rupture of Diaphragm. May accompany crushing injuries of the chest or abdomen, or compression injuries. Suggested by epigastric pain and distress and hyperresonant percussion note at the left base with absent or diminished breath sounds X-ray. Posterior portion of left side of diaphragm usually is involved The stomach, a large part of the colon, the spleen, and loops of small intestine may lie in the left part of the chest. Right-sided rupture is rarer and is associated with displacement of the liver and colon.

(*a*) *First Aid* Rest Morphine Treat for shock Administer blood or plasma Withhold food by mouth if there is distention, distress or vomiting Nasal tube drainage of stomach

(*b*) *Definitive Treatment* Many of these patients will be subjected to laparotomy under suspicion that a ruptured viscus is present. Repair diaphragm either via laparotomy or thoracotomy incision Laparotomy is preferable for early cases without adhesions If repair is done transpleurally, crush phrenic nerve

16. Blast Injuries. Impact of the blast wave from the nearby explosion of a bomb or shell may cause extensive damage to the lung without evidence of external injury. Blood or blood-tinged fluid may trickle from the nose or mouth Profound shock may appear promptly or within a few hours

(*a*) *First Aid* Rest. Morphine in small amounts Atropine Oxygen

(*b*) *Definitive Treatment* Oxygen Supportive treatment for shock, employing blood substitutes in preference to whole blood Atropine Avoid anesthesia by inhalation

CHAPTER III

COMPLICATIONS AND SEQUELAE OF THORACIC INJURIES

PNEUMOTHORAX

AIR may enter the pleural cavity from without, through a penetrating wound from within, from wounds of the lung, bronchi or esophagus; or rarely gas may be formed in the pleural space by gas-forming micro-organisms.

Evacuation by airplane of patients who have pneumothorax may cause fatal respiratory embarrassment.

Types of Pneumothorax

A *closed pneumothorax* has no communication with the outside through the thoracic wall. It may have been produced by air escaping from the lung or by air entering a penetrating wound of the thoracic wall that subsequently has become closed. An *artificial pneumothorax* is a closed pneumothorax induced for therapeutic purposes. A *spontaneous pneumothorax* is a closed pneumothorax produced by the rupture of a bleb on the surface of the lung. It is usually not due to direct trauma but occasionally is produced by aspiration with a needle.

Bilateral closed pneumothorax can be tolerated if the amount of air in the pleural cavities is not too great. *Bilateral open pneumothorax* is rapidly fatal unless the openings are small.

Pressure pneumothorax ("valvular" pneumothorax or "tension" pneumothorax) results from valve-like rupture of the lung or air passages, through which, when the patient coughs or strains, air is forced into the pleural cavity. A high pressure is built up, causing collapse and compression of the injured lung and reduction in the volume of the opposite lung by displacement of the mediastinum toward the opposite side. Pressure pneumothorax is a more frequent complication of crushing injuries than of penetrating wounds.

Open pneumothorax is produced by a wound that creates a defect in the thoracic wall, causing free communication between the

pleural space and the outside air. Its harmful effects are a resultant of the size of the opening and the initial vital capacity of the individual On inspiration air is drawn into the pleural cavity. For this reason, the condition is known as a *"sucking" wound* An open pneumothorax is much more dangerous than a closed one. In the former, not only are there serious pressure disturbances which affect the ability of both lungs to take in air, but also, because of the swinging motion of the mediastinum (mediastinal flutter), there is movement of air from the more collapsed to the less collapsed lung during inspiration and in the reverse direction during expiration (pendulum air). As a result, both respiration and circulation are seriously impaired The normal intake of fresh air into the lungs is diminished and the pressure disturbances likewise interfere with the passage of blood along the large mediastinal veins and with the filling of the auricles In addition to the serious consequences of open pneumothorax already mentioned, the pleura is exposed to gross contamination by the sucking in of air, and considerable loss of heat occurs by the excessive ventilation of the pleural cavity with the to and fro passage of air On the other hand, with closed pneumothorax there is less serious pressure disturbance, unless too great tension has been caused by excessive introduction of air in artificial pneumothorax, and the circulation of blood is much less likely to be seriously impaired The dangerous pressure pneumothorax mentioned in the preceding paragraph is not a closed pneumothorax despite the absence of a communicating wound through the thoracic wall

Open pneumothorax exists during operations in which the parietal pleura is incised so that air enters the pleural space Under these circumstances, the deleterious effects are controlled by differential pressure anesthesia

Diagnosis

Symptoms of respiratory insufficiency, cardiac embarrassment and peripheral circulatory failure in the various types of pneumothorax depend on the volume of lung that is collapsed, the rapidity of onset, the degree of mediastinal displacement and the initial vital capacity of the patient. Open pneumothorax and pressure pneumothorax produce a dangerous or fatal degree of respiratory decompensation whereas simple, unilateral, closed pneumothorax may be well tolerated.

Percussion gives a hyperresonant note, auscultation elicits distant or absent breath sounds The mediastinum is displaced toward the opposite side Displacement of the mediastinum is detected by

(1) palpation of the trachea in the suprasternal notch, (2) palpation of the apex impulse, (3) auscultation for maximal intensity of cardiac sounds, (4) percussion of cardiac dulness.

Treatment

Closed Unilateral Pneumothorax.—This demands no treatment other than rest and sedation unless the air contained in the chest is under positive pressure or large in amount; then it is aspirated.

Pressure Pneumothorax. First Aid Treatment—Any measure that allows the air to escape will relieve pressure and reduce dyspnea. A short needle of large caliber (15 gauge) is inserted into the second intercostal space anteriorly at least 1 inch (2.5 cm.) from the sternal border The needle is left in place only if air continues to escape under pressure. If a large needle is not available, an incision through the thoracic wall, with introduction of a catheter or small tube, will do. The patient is placed on the affected side

Subsequent Treatment—If air continues to escape under pressure the needle is replaced by a small catheter introduced through a cannula and connected as in a closed drainage system. The catheter is removed as soon as air ceases to escape, usually in from twenty-four to forty-eight hours. If the pneumothorax shows no tendency to recur further treatment is unnecessary

Open Pneumothorax ("Sucking" Wound)—This condition is always serious and the larger the opening into the thorax the greater the danger It is essential that open wounds of the thoracic wall be closed at the *earliest possible moment* If facilities for final closure are not available at the first-aid station, temporary closure must be made and the patient transferred as quickly as possible to an adequately equipped station.

First Aid Treatment—Immediate airtight closure by suture should be effected when possible. If because of excessive tissue loss or for other reasons it is not possible to close the opening by suture, it should be closed temporarily by adhesive plaster rubber dam, a large pad of vaseline gauze or moist dressings, or any other means at hand.

Subsequent Treatment.—An X-ray film should be made for the detection and localization of foreign bodies. If infection has not developed, thorough débridement should be performed, including removal of foreign bodies and devitalized tissue from the thoracic wall, thoracic cavity and lung. If possible to do so without tension, the various layers of the thoracic wall should be approximated. If this is not possible, closure can be accomplished by one of the following

methods (Fig. 1) (1) If the wound involves the lower portion of the thoracic wall, the diaphragm can be paralyzed and then sutured to the margins of the wound. To paralyze the diaphragm the phrenic nerve is crushed transpleurally, or a small incision is made above the clavicle and the nerve pinched with a hemostat. (2) In the upper portion of the thorax, such broad, heavy muscles as the pectoralis major, the latissimus dorsi or the trapezius can be mobilized and

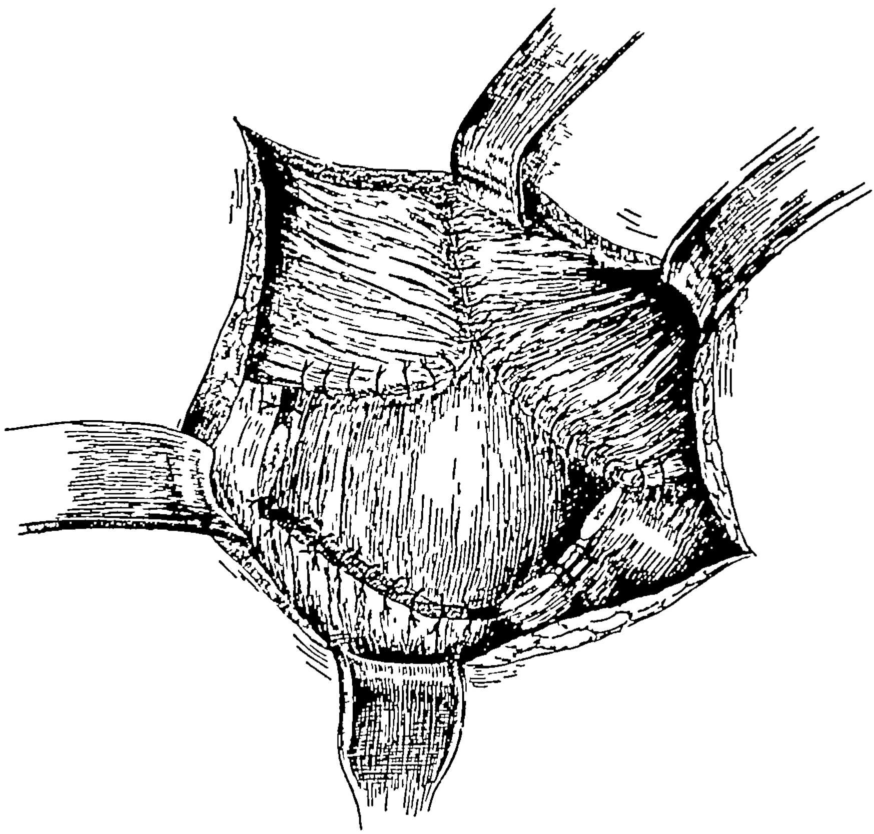

Fig. 1—Repair of large defect in the midportion of the thoracic wall by the combined use of the diaphragm and such heavy, flat muscles as the latissimus dorsi and pectoralis major

sutured over the defect. If none of these measures is applicable, closure can be obtained by suturing the lung to the margins of the wound, then covering the area by a gauze pack. The skin can be mobilized and advanced for suture by relaxing incisions

If active infection already has developed the tissues of the thoracic wall can be approximated snugly by the use of adhesive plaster. Suture of muscles or plastic operations that bring parts together under tension are to be avoided. In the presence of gross infection the

opening can be closed by an occlusive pack made of rubber sheeting or gauze impregnated with vaseline. The pleural cavity itself should not be packed or gauze placed against the mediastinum. The pleural space is drained by an intercostal catheter preferably in a dependent position away from the wound in the thoracic wall, and connected with an underwater tube. When an occlusive pack is employed it is sutured to the skin so it cannot be drawn into the chest. The patient is kept on the injured side until pleural adhesions form and the mediastinum becomes stabilized.

EMPHYSEMA

Types

Subcutaneous or *"surgical" emphysema* is produced by air entering the tissues at the site of injury in the thoracic wall. The air usually is forced out into the tissues by the head of pressure in a pressure pneumothorax. Rarely it comes directly from an injured adherent lung.

In *mediastinal emphysema* the air enters the loose, areolar tissues of the mediastinum from wounds of the trachea, larger bronchi or esophagus. Air also may be drawn into the mediastinum through low cervical wounds. Crepitation first appears above the sternal notch and spreads from that point as subcutaneous emphysema. Compression of the large veins by the air in the mediastinum interferes with the return of blood to the heart and thereby reduces the cardiac output. The result is circulatory failure that may progress to death.

Diagnosis

Crepitation in the tissues is readily detected by palpation. During auscultation of the chest it produces an audible crackling. Coarse crepitation, synchronous with the heart beat, can be heard in the presence of mediastinal emphysema when the patient holds his breath. With mediastinal emphysema there may be intense dyspnea, cyanosis and engorgement of the veins of the head and neck. Subcutaneous emphysema in itself rarely produces serious consequences in spite of the terrifying appearance in an extreme case.

Both types of emphysema are to be differentiated from gas phlegmon. A normal temperature and pulse rate are in favor of the former while induration and edema associated with fever and leukocytosis suggest the latter

Treatment

Subcutaneous Emphysema.—When subcutaneous emphysema is progressive and extensive, usually it comes from pressure pneumo-

thorax or mediastinal emphysema Treatment of the primary condition is therefore indicated In the rare instance in which the air is coming from an adherent lung, incision of the thoracic wall down to the pleura, with débridement of the wound, will be effective. Multiple incisions for the escape of air from the tissues are rarely indicated

Mediastinal Emphysema—This may require immediate and radical first-aid measures Urgent symptoms demand a suprasternal incision to provide decompression of the mediastinum If laryngeal obstruction is present, tracheotomy or intubation must be added

HEMOTHORAX

Definition

Hemothorax results from hemorrhage into the pleural cavity from the thoracic viscera, the thoracic wall or from both sources The blood tends to remain fluid, probably because it is defibrinated by the motions of the lungs and heart

Diagnosis

A man may bleed to death into a pleural cavity, yet only the classical signs and symptoms of hemorrhage, plus the physical signs of fluid in the chest, may be evident. The presence of the amount of blood that represents a fatal hemorrhage will not in itself produce serious mechanical disturbances of respiration Respiratory difficulties may be produced by an associated pneumothorax, or may appear later due to the superimposed traumatic effusion

Hemothorax is to be differentiated from (1) massive pulmonary collapse, (2) rupture of the diaphragm, (3) pleural effusion and (4) consolidation

Massive Collapse of the Lung—In hemothorax, as with pleural effusion, the breath sounds are diminished but may be bronchial in character Egophony is present and there may be hyperresonance above the area of dulness In the presence of massive collapse, the breath sounds are absent or diminished Most important, however, is the displacement of the mediastinum (trachea and heart) toward the dull side in cases of massive collapse and away from the dull side in cases of hemothorax.

Rupture of the Diaphragm with Displacement of the Abdominal Viscera into the Thoracic Cavity—Peristaltic sounds heard by auscultation may be suggestive but usually x-ray examination is required to establish this diagnosis

Pleural Effusion of Infectious Origin.—This may be differentiated only by thoracentesis.

Consolidation of a Contused or Pneumonic Lung.—This is accompanied by increased, rather than diminished or absent, tactile fremitus and intense bronchial breath sounds, in contrast to the diminished bronchial breathing or absent breath sounds of hemothorax.

Treatment

See Chapter I, "Hemorrhage and Shock," p. 223 Chapter II 8 (C) "Penetrating Injuries with Shock and Hemorrhage from Laceration of Lung," p. 232 and this chapter "Infected Hemothorax," p. 248.

EMPYEMA OF THE PLEURA

Diagnosis

Empyema is characterized by the signs and symptoms of sepsis; a dull or flat percussion note, diminished or absent tactile fremitus, distant bronchial breathing or absence of breath sounds displacement of the mediastinum toward the opposite side and intercostal tenderness and limitation of the respiratory excursion on the affected side. Collections of pus encapsulated in the interlobar fissures, between the lung and the diaphragm, or medially between the lung and mediastinum, are more difficult to diagnose. In such cases, localization is made by x ray in various positions.

The final diagnosis is made by means of the aspirating needle. The site of thoracentesis is selected on the basis of physical signs and localization by x-ray Diagnosis is often delayed because thoracentesis is limited to conventional sites.

Common mistakes in the management of empyema are (1) the selection of too low a point for diagnostic puncture, (2) selection of too high a site for surgical drainage and (3) the use of open drainage before actual, frank pus is present.

Unless foul-smelling pus is obtained on thoracentesis, drainage is delayed until bacteriologic examination has been made by smear or culture. Adherence to this rule, military exigencies permitting, not only will prevent the disastrous consequences of draining an unmixed tuberculous effusion but will provide a rational guide to chemotherapy and be helpful in the management of certain complications that appear at a later date.

Types of Empyema and Their Treatment

See Chapter I, "Drainage of the Pleural Cavity"

An understanding of types and stages of empyema is essential to

their proper treatment. A fairly close analogy can be drawn with the modern concepts of the management of peritonitis

Diffuse Pleuritis (Acute Empyema)—In its early stages empyema is a generalized infection of the pleural cavity characterized by accumulation of thin, cloudy fluid in the dependent portion This fluid contains pus cells and micro-organisms. In lobar pneumonia (pneumococcal) it appears after the pulmonary infection is full-blown. In streptococcal infections the fluid appears early, is large in amount and may mask the underlying bronchopneumonia Drainage at this stage does not help the infection and may produce fatal complications Aspiration with a needle is done to relieve serious encroachment on pulmonary volume, especially if the respiratory reserve is further reduced by bronchopneumonia of one or both lungs. Aspiration is undertaken when the fluid is causing respiratory embarrassment Under no circumstances should the creation of open drainage be considered at this time because it would add the harmful effects of open pneumothorax Rib resection is contraindicated in this stage Under favorable circumstances a catheter may be inserted intercostally with airtight technic, if this is done, closed drainage should be rigidly maintained for at least fourteen days, at the end of which time the lung will be adherent to the thoracic wall and open drainage or supplemental rib resection is permissible When constant personal supervision by a surgeon experienced in this technic is impossible, it is better to rely on aspiration by needle, repeated when necessary and supplemented by chemotherapy

Encapsulated Abscess of the Pleura (Encapsulated Empyema)—When the infection becomes localized, the adhesions around the abscess bind the lung to the thoracic wall The pus becomes thick, and large masses of fibrin may be present. The pneumonia usually has subsided when this stage has been reached but fever and leukocytosis continue or reappear after a brief subsidence X-ray demonstrates localized opacity

In cases of encapsulated empyema drainage is by rib resection after the diagnosis has been confirmed by thoracentesis The dependent region of the pocket is localized by means of the aspirating needle with the additional aid of the x-ray film Rib resection is performed and a finger inserted to determine whether the opening is really at the bottom of the cavity If it is more than one rib from the bottom, a second rib resection is made that is at the dependent portion of the cavity Intercostal trocar-catheter drainage is not suitable for drainage in cases of encapsulated empyema The blind thrust of a trocar may damage an adherent lung, and there is no cer-

tainty of obtaining dependent drainage. Also, thick pus and fibrin are difficult to evacuate through a catheter

Massive or Total Empyema.—When massive collections of thick pus have separated the apex of the lung from the thoracic wall, drainage is managed so that there may be slow evacuation of the pus without admission of air The lung then expands as the pus is drained and becomes adherent to the thoracic wall. Aspiration by needle or an intercostal catheter might accomplish this but the hydrostatic pressure of the massive empyema tends to force pus into the tissue planes of the thoracic wall adjacent to a puncturing opening. It is better to use the wider opening of a rib resection, but on opening the pleura a large tube that is connected with a closed drainage water-seal should be quickly inserted. A vaseline gauze pack is placed about the tube allowing free vent for pus that escapes around it. The tube is kept clamped most of the time but it is opened every four hours (intermittent closed drainage) to allow approximately 200 cc. of pus to drain until the chest is empty Then the clamp is removed and constant closed drainage is continued as long as the connection between tube and thoracic wall remains airtight.

Mixed Infection (Anaerobic) Empyema.—When foul pus is obtained at diagnostic thoracentesis, operative drainage becomes an urgent procedure to prevent a phlegmon of the thoracic wall spreading from the needle tract. Foul empyema is often complicated by bronchopleural fistula as the empyema commonly originates from a focus of necrotizing pneumonitis or an early lung abscess. Pneumothorax may already be present from this source. If a patient is expectorating foul pus, diagnostic thoracentesis is performed with the patient on the operating table and facilities for immediate drainage at hand.

The infection is usually so virulent that treatment must be undertaken before encapsulation has taken place. According to the principles stated above, aspiration by needle or intercostal drainage might be thought preferable however the hazards of phlegmon of the thoracic wall are so great that a modified form of rib resection may be undertaken. A large tube is quickly inserted through the incision into the pleura and connected with a water-seal valve. Constant closed drainage is maintained. No sutures are placed in the thoracic wall, the tube being surrounded with a vaseline gauze pack.

If the patient is extremely ill and hospital facilities poorly adapted to the maintenance of constant closed drainage, one of two alternative procedures may be followed (1) A 3 inch (about 7.5 cm.) incision is made down to the rib and intercostal space under

their proper treatment. A fairly close analogy can be drawn with the modern concepts of the management of peritonitis

Diffuse Pleuritis (Acute Empyema)—In its early stages empyema is a generalized infection of the pleural cavity characterized by accumulation of thin, cloudy fluid in the dependent portion This fluid contains pus cells and micro-organisms. In lobar pneumonia (pneumococcal) it appears after the pulmonary infection is full-blown. In streptococcal infections the fluid appears early, is large in amount and may mask the underlying bronchopneumonia Drainage at this stage does not help the infection and may produce fatal complications Aspiration with a needle is done to relieve serious encroachment on pulmonary volume, especially if the respiratory reserve is further reduced by bronchopneumonia of one or both lungs Aspiration is undertaken when the fluid is causing respiratory embarrassment Under no circumstances should the creation of open drainage be considered at this time because it would add the harmful effects of open pneumothorax. Rib resection is contraindicated in this stage Under favorable circumstances a catheter may be inserted intercostally with airtight technic; if this is done, closed drainage should be rigidly maintained for at least fourteen days, at the end of which time the lung will be adherent to the thoracic wall and open drainage or supplemental rib resection is permissible When constant personal supervision by a surgeon experienced in this technic is impossible, it is better to rely on aspiration by needle, repeated when necessary and supplemented by chemotherapy.

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to the same principles that apply to wounds of other soft parts. In removal of the foreign bodies and in débridement of the wound, due care is taken to avoid opening the pleural cavity

Pleura and Lung

The demonstration of a metallic foreign body in pleura or lung is not in itself an indication for intervention. When the damage to the thoracic wall or lung by traverse of the missile is so minimal that débridement can safely be omitted or limited to excision of the margins of the wound, open thoracotomy for extraction of a metallic foreign body from the lung or pleura is deferred until careful appraisal of the situation can be made. When thoracotomy is necessary as a step in the débridement of a penetrating wound, or when progressive intrapulmonary hemorrhage makes thoracotomy mandatory foreign bodies are removed at the same time if the condition of the patient permits. The information afforded by preliminary x-ray films or fluoroscopy is of great value in the management of thoracic casualties.

Smooth-surfaced projectiles, such as small-arm missiles, or very small fragments of high explosive missiles become encysted and may remain in the pleura or lung without causing symptoms. Large, irregular or jagged fragments of high explosive missiles lodged in the pleura lead to empyema embedded in the substance of the lung, they may produce suppuration and hemorrhage, although these sequelae may be delayed for years.

As facilities for radical thoracic surgery are not commonly available in advanced casualty stations, the problem of the retained projectile usually will be encountered (1) after infection has become established, (2) after active infection has subsided, (3) after it is apparent that immediate infection is not to be reckoned with, or is localized to the thoracic wall.

After Infection Has Become Established.—During the acute phase of infection the foreign body is removed only if it is easily accessible during rib resection for empyema or drainage of a lung abscess. Otherwise treatment is directed toward controlling the infection with chemotherapy supplemented by the drainage of localized sites of pleural or pulmonary suppuration.

After Active Infection Has Subsided—If a chronic sinus persists, perpetuated by an infected foreign body in the pleura, operation is undertaken for its removal. Chronic suppuration around a pleural foreign body may establish internal drainage through a bronchopleural fistula, causing repeated hemoptysis or purulent sputum.

local anesthesia Aspiration by needle is carried out through the interspace. The incision is then dusted with a sulfonamide and packed with gauze Further aspiration can be performed when required by removal of the gauze pack, which is replaced on completion of the procedure. (2) A 3 inch incision is made as above and trocar-catheter drainage established. The incision is dusted with a sulfonamide and packed open with gauze. If conditions permit a delay of six to twelve hours between making the incision and inserting the catheter, a protective local inflammatory reaction may be produced by sulfonamide dusting and gauze packing during the interval

Infected Hemothorax—Uninfected hemothorax not infrequently causes fever of low grade and leukocytosis Diagnosis of infection, as in empyema, depends on the demonstration of bacteria by smear or culture following thoracentesis

The condition resulting from a collection of blood and fibrin in a pleural cavity infected by organisms of pathogenicity of low grade, if the infection is not perpetuated by suppuration of the lung or thoracic wall, or by a bronchial fistula, may be treated by thoracotomy, thorough cleansing of the pleural cavity, local and systemic chemotherapy and primary closure Much time may be saved by this procedure If an effusion reaccumulates, aspiration and irrigation with saline solution may be tried Repeated accumulation of infected fluid requires drainage as for empyema

Grossly infected hemothorax, with manifest signs of sepsis, is treated as other forms of empyema

Chronic Empyema—The most frequent causes of chronic empyema are tuberculosis, inadequate or nondependent drainage, foreign bodies, bronchial fistula and undiscovered, unopened pus pockets If these causes are sought and the condition found is energetically treated, chronic nontuberculous empyema will be prevented

The need for extensive operations (Schede, Keller) will be greatly diminished if empyema is treated correctly from the start and if, when healing does not occur, the cause of the chronicity is promptly sought and appropriately treated Extensive thoracoplasty for chronic disease is not undertaken until simpler methods have been given a thorough trial (several months) and the patient has been evacuated from the combat zone See Chapter I, "Problems of Convalescence"

FOREIGN BODIES

Chest Wall

Conditions resulting from retained projectiles or other foreign bodies in the soft parts of the thoracic wall are managed according

words, the symptoms and signs which may indicate immediate treatment are due to the wound of the heart and not to the foreign body itself. Furthermore, foreign bodies free in either of the ventricles are likely to be thrown out into the circulation spontaneously and, if this does not occur such an event can be aided by placing the patient in such a position that gravity will aid in carrying the body out of the heart. The subsequent procedure is explained in the next paragraphs.

Foreign Body Entering the Pericardium and Heart by Penetrating the Pericardium.—Treatment is directed to the wound of the heart rather than to the foreign body with certain exceptions. If operation is indicated by recurring tamponade or continued loss of blood, as is likely to be the case when a large missile penetrates the wall of one of the cardiac chambers, and if the foreign body is readily accessible, it is removed, especially if it is so irregular in shape as to make it probable that organic material (clothing) has been carried in with it.

A small, smooth missile free in the cavity of the thick walled *left* ventricle may be difficult to palpate and even more difficult to keep in a fixed position for removal, so an attempt is made by postural changes (under fluoroscopic control) to throw it into the peripheral circulation. If this is done, the carotid arteries, especially the left one, should be compressed until the foreign body has passed beyond the arch of the aorta. The body may then be removed from a peripheral vessel more safely than from the heart.

A foreign body free in the cavity of the *right* ventricle may in most instances be handled in the same manner as one in the left ventricle. Unless it is irregular or of exceptional size, posture is utilized to throw it into the pulmonary circuit where it will be well tolerated. When operation is undertaken for the relief of tamponade or control of hemorrhage, an attempt is made to identify and remove the missile. Since the wall of the right ventricle is not so thick as that of the left ventricle, palpation and fixation of the body through the ventricular wall is less difficult.

Whether or not the missile is removed, the patient is observed for the development of infection in the pericardium and pleura and appropriate modifications of treatment are made for its development.

Foreign Body Entering a Cardiac Chamber through Venous Channels (from a Peripheral Source into the Right Ventricle and from a Pulmonary Vein into the Left Ventricle).—These bodies are rarely more than 1 to 1.5 cm. in diameter and may therefore be thrown into the pulmonary or peripheral circulation, as the case may

External drainage may never have been present or an external sinus may have closed spontaneously The treatment is thoracotomy, with extraction of the foreign body and drainage of the encapsulated empyema

A foreign body in the substance of the lung may form the nucleus of an acute lung abscess Here again, indications for treatment are centered on the abscess, the presence of a foreign body points toward the necessity for external drainage rather than expectation of spontaneous healing If infection of the lung subsides under rest and chemotherapy, and reaches a chronic phase, or if, after long residence in the lung, chronic bronchopulmonary infection develops in the region of the foreign body, resection of the irreparably damaged lobe or lobes may be preferable to drainage and extraction of the foreign body. This and similar decisions are matters for the consultation services and special facilities of a general hospital concerned with the ultimate disposition of casualties

After It Is Apparent that Immediate Infection Is Not to Be Reckoned with, or Is Localized to the Thoracic Wall—Chemotherapy is continued until healing of the thoracic wall has become complete and resorption of pleural blood and effusion has taken place. Reparative processes in a contused lung are recognized by clearing of x-ray opacities and return of normal ventilation

Removal of large, irregular fragments of high explosive missiles from either pleura or lung may then be undertaken as an operation of election As in cases in which infection is present, lobectomy may be preferable to pneumonotomy, and again, decision may properly be deferred to hospitals concerned with discharge of men from active service and with rehabilitation

In contrast to foreign bodies that have been aspirated, penetrating missiles embedded in the lung cannot be removed by bronchoscopy If reasonable doubt exists regarding the origin or nature of a foreign body, bronchoscopy is indicated

Pericardium and Heart

In any discussion of foreign bodies in the heart it is important that distinction be made between those carried to one of the cardiac chambers by venous channels and those which have entered the heart by direct penetration The former group may give rise to few if any symptoms or signs referable to the heart and, in the latter group, the symptoms and signs in most instances will be due to damage caused by the penetration of the pericardium and heart rather than to the presence of the foreign body within those structures In other

removal is a simple matter Infection of the fused cartilages is difficult to overcome it is especially important to avoid injury to them when operating in the presence of infection. This warning applies particularly to pericardiostomy for suppurative pericarditis. Because of this danger single cartilages (the fourth and fifth) are chosen for resection in draining the pericardium rather than the fused cartilages, as is frequently recommended.

LUNG ABSCESS

Etiology

Lung abscess follows infection of contused and lacerated portions of lung. Aspiration abscess occurs among debilitated men who have difficulty in swallowing (wounds of the neck, tongue, mouth, jaws) among men who have lain unconscious in the field (head injuries) and among drunken or unconscious men who have aspirated vomitus. Lung abscesses may also follow immersion, particularly in sewage-contaminated waters. Immediate bronchoscopic aspiration is employed as a preventive measure when there is reason to believe that vomitus or other foreign matter has entered the air passages.

Diagnosis

Lung abscess is characterized by signs and symptoms of sepsis, by cough, at first unproductive, then with sputum which is blood-tinged at first and later is frankly purulent and foul. The region surrounding the abscess may be dull, breath sounds may be bronchial or (rarely) amphoric and accompanied by coarse, dry or moist râles. However the physical signs are so frequently not significant that the diagnosis as well as the localization must be made by x ray Sedation and atropine are dangerous when expectoration is copious even codeine may stop expectoration and cause aspiration pneumonia in weakened men, while atropine makes the sputum tenacious and difficult to evacuate.

Treatment in Acute Stage

If the patient is toxemic, has a high temperature or a spreading process is present, do not attempt strenuous "postural drainage" but let the man lie on his diseased side. This will diminish cough and splint the infected side, thus preventing spread and permitting the fever and toxicity to abate. The abscess usually will localize and form a cavity with a fluid level.

After the abscess has become localized, conservative treatment with postural drainage is the rule for the first four to six weeks.

be, by posture. If this is not possible or advisable, treatment is conservative until careful appraisal can be made. Unless operation is indicated for other reasons, a foreign body in the pericardium, cardiac wall, or cardiac chamber is left until maximal improvement in the patient's general condition has occurred. The decision as to removal is then based on the severity of symptoms balanced against the probable danger of removal. It is certain that it is not necessary to remove all such foreign bodies even when they lie in a cardiac chamber If a foreign body is at first free in a cardiac chamber and later becomes fixed in position, it is not disturbed

INFECTIONS OF THE THORACIC WALL

Acute Infections

Acute infections of the thoracic wall, especially those due to gas-forming organisms, are likely to spread with remarkable rapidity because of the extensive muscular and fascial planes of the pectoral and subscapular regions. The more serious infections follow wounds in which there is extensive destruction of tissue Careful débridement is therefore important in the treatment of wounds of the thoracic wall. Serious infections of the thoracic wall may also follow the injudicious use of the aspirating needle in cases of lung abscess or putrid empyema

Treatment—The treatment of such infections is wide incision—slightly beyond the obvious limits of involvement—excision of necrotic tissue, especially muscle, and local and systemic use of chemotherapy and immunotherapy

Chronic Infections

Persistent draining sinuses of the thoracic wall (excluding the chronic granulomas such as tuberculosis and actinomycosis) usually indicate a residual foreign body or infection of the ribs or costal cartilages Osteomyelitis may result when fractured ribs become infected in cases of compound injury This is likely to occur when fragments of rib, uncovered by periosteum, are left in the infected field The uncovered portions of rib sequestrate and act as foreign bodies The sinuses will persist until these sequestra have been removed Infection of the ends of ribs may occur following rib resection for drainage of empyema, especially if portions of rib are left uncovered by periosteum

Infection of a costal cartilage is likely to persist until the infected cartilage has been removed When single cartilages are involved,

the location and extent of injury to the heart and on whether or not there is free communication between the pericardial cavity and the pleural cavity or between the pericardial cavity and the outside.

Hemopericardium with Tamponade

Cardiac tamponade occurs in its most characteristic form when one of the chambers of the heart is penetrated by a missile that traverses that portion of the precordial space which is not covered by pleura. Blood rapidly fills the inelastic pericardial sac. As this occurs, the wound in the parietal pericardium is displaced from the corresponding opening in the thoracic wall and the blood is trapped within the pericardium. The pressure within the pericardial sac soon becomes equal to the pressure in the great veins and the circulation temporarily approaches a standstill. As the venous pressure rises blood enters the heart in small quantities, thus temporarily maintaining the circulation, but at a low level of efficiency While death may ensue rapidly such patients frequently survive for a considerable time if given proper conservative treatment. If the wound in the wall of the heart is small, it may become sealed off during the period of circulatory collapse. It is for this reason that pericardicentesis is recommended when cardiac tamponade is not complicated by bleeding into the pleural cavity If the intrapericardial pressure is reduced by pericardicentesis and remains low as indicated by recovery of arterial blood pressure and reduction of abnormally high venous pressure, one may conclude that the bleeding has stopped and that conservative treatment should be continued.

The signs and symptoms of cardiac tamponade are circulatory collapse, out of proportion to evident loss of blood low systolic pressure, low pulse pressure high venous pressure (distended external jugular veins) pulse rate (if pulse is palpable) slow in relation to systolic blood pressure, distant, muffled heart sounds, paradoxical pulse (weaker on inspiration) and apparently immobile cardiac shadow on fluoroscopy

First Aid Treatment.—This consists in complete rest and administration of morphine in required dose and of atropine, 1/50 grain (0.00132 gm.) If pericardicentesis is not satisfactory or if the pericardium refills promptly immediate operation is indicated.

Subsequent Treatment.—Postoperatively, oxygen therapy is advisable. Tamponade may recur from serous effusion or because of infection. Serous effusion is treated by aspiration, repeated if necessary Infection demands early pericardiostomy

Operation is indicated only for localized abscess. Before operation is attempted the abscess must be very carefully localized by x-ray films, fluoroscopy and, if necessary, bronchoscopy. *Do not aspirate* until the pleura has been exposed at operation

MASSIVE HEMORRHAGE INTO THE SUBFASCIAL SPACES OF THE THORACIC WALL

Diagnosis

The subfascial spaces of the thoracic wall, particularly those of the subpectoral and subscapular regions, are so extensive that a massive, dissecting hemorrhage from a wounded artery may cause exsanguination When rapid swelling, with fluctuation and dulness on percussion, follows an injury in one of these regions, steps are taken to control the bleeding

Treatment

A compressing elastic dressing (marine or rubber sponge if available) is applied immediately and the man treated for hemorrhage. Usually a firm pressure dressing controls the hemorrhage and, as intervention is both difficult and hazardous, every effort is made to avoid open operation

With continuing hemorrhage, especially from the axillary artery, the vessel may be exposed and both proximal and distal ends ligated Incision and dissection for this purpose are kept minimal to avoid damage to collateral vessels If the axillary artery is ligated the concomitant vein is ligated and the sympathetic fibers to the arm are blocked with procaine

WOUNDS OF THE HEART

Types

Wounds of the heart may result in external hemorrhage or hemorrhage into the pleural cavity, or blood may be trapped in the pericardium. If blood is able to pass out of the pericardium as rapidly as it flows from the heart, there is no evidence of cardiac compression and the symptoms and signs are those of hemorrhage alone When blood is forced into the pericardial sac more rapidly than it can drain out, as is the rule when one of the ventricles is injured, the symptoms and signs of cardiac tamponade (compression) are added to signs of hemorrhage When the lung is also injured, there may be both air and blood in the pericardium as well as in the pleural cavity The symptoms, signs, treatment, and prognosis therefore depend on

CHAPTER IV

OPERATIVE SURGERY

AUTOTRANSFUSION OR REINFUSION OF CITRATED BLOOD

IF transfusion is imperative and blood or a satisfactory substitute cannot be procured, autotransfusion may be indicated, although the procedure is not without risk and never should be employed when sterility of the fluid is questionable.

Technic

Blood can be removed from the pleural cavity by aspiration with a needle, by trocar and catheter or in the event of thoracotomy by a suction tube. If the last mentioned method of collecting the blood is used, the suction tube is flushed out with a 2.5 per cent solution of sodium citrate preliminary to, and at intervals during, removal of the blood. The final mixture must contain at least 0.25 per cent sodium citrate and any large excess of sodium citrate must be avoided. Blood and sodium citrate are gently mixed during the aspiration, filtered through at least twelve layers of fine mesh gauze, then promptly reinfused under sterile precautions.

BRONCHOSCOPY AND TRACHEAL INTUBATION

Bronchoscopy requires a specialized technic and usually will be assigned to specialists familiar with its performance.

Intubation of the trachea, in order to aspirate blood and secretions from the lower air passages, may be a life-saving measure and can be done by any surgeon after anesthetization of the larynx, which is essential.

If the patient can be placed in a sitting position and can be made to pull out his tongue by grasping it with a piece of gauze held between the thumb and forefinger anesthesia can be accomplished by spraying the throat with an atomizer containing 2 cc. of one of the following (1) pontocaine 2 per cent, (2) cocaine hydrochloride 10 per cent, (3) metycaine 5 per cent, or (4) procaine hydrochloride

Hemopericardium with Tamponade Plus Massive Hemothorax

This combination of findings indicates a particularly serious situation, for the occurrence of tamponade, even though blood is escaping into the pleural cavity, almost certainly means that there is a large wound of one of the ventricles. Patients with such injuries rarely survive to reach a first-aid station. The diagnosis is not especially difficult, for no other condition gives acute cardiac compression and massive hemothorax. The only chance of saving such a patient is by immediate transpleural thoracotomy with cardiorrhaphy. Even though the prognosis is extremely grave, operation may be undertaken if circumstances permit.

Hemopneumopericardium

Occasionally, when a missile penetrates both the lung and the pericardium, air and blood are demonstrable in the pericardial cavity as well as in the pleural cavity. This finding is significant, for when one of the cardiac chambers is penetrated, the pericardial cavity rapidly fills with blood, and air is thereby excluded. Therefore, the presence of both blood and air in the pericardium indicates a tangential wound involving the pericardium and wall of the heart. The condition is suggested by a splashing or churning sound heard over the precordium and synchronous with the heart beat. X-ray films made with the patient in the upright or lateral recumbent position confirm the diagnosis.

First-Aid Treatment.—If bleeding is only slight, conservative treatment is indicated. If there is a large collection of blood in the pleural cavity it is removed by aspiration with a needle. If the bleeding is from a small cardiac wound or a coronary vessel of medium size, transfusion may tide the patient over until he can be transferred to a hospital with facilities for major surgery.

Subsequent Treatment.—If there is no reaccumulation of blood following aspiration, conservative treatment is continued. If bleeding persists or recurs, transfusion and operation should be performed immediately under positive pressure anesthesia. Since the pleural cavity already has been penetrated, the heart is exposed by a long incision through the fourth or fifth interspace and the wound or wounds of the heart are repaired.

needle remains and immediate operation is performed. See Chapter III "Mixed Infection Empyema" (p. 247)

When a free flow of blood is obtained in aspiration of hemothorax, and it is desired to maintain collapse of the lung by pneumothorax, (1) a second needle may be inserted to admit air as blood is withdrawn, (2) air may be injected with the same syringe, 50 cc. after each 50 cc. of blood has been aspirated or (3) the trocar-catheter method may be employed.

In aspiration of fluid from the pleural cavity without replacement of air it is inadvisable to remove more than 600 cc. at a single sitting as expansion of the compressed lung provokes pulmonary edema.

PERICARDICENTESIS

Pericardicentesis may be used as a diagnostic procedure if tuberculous pericarditis or suppurative pericarditis is suspected. It is used as a therapeutic measure for relief of acute or subacute cardiac compression from hemorrhage or effusion. It has no place in the treatment of acute suppurative pericarditis other than to give temporary relief from pressure. The insertion of a needle into the pericardium is not without danger for there is always the possibility of injuring an important coronary artery. In the presence of suppurative pericarditis, if the needle is passed through the pleura or peritoneum as well as the pericardial sac, contamination results. In cases of traumatic hemopericardium, aspiration of blood may temporarily relieve circulatory collapse and give time for proper preparation for operation. In some instances, hemorrhage will not recur and aspiration will give permanent relief.

The two commonly used routes for pericardicentesis are the left costoxiphoid and the left parasternal routes the latter is used more frequently than the former The left parasternal route is reasonably satisfactory when there is a large amount of fluid in the pericardial sac and no adhesions between the anterior pericardium and epicardium. However since fluid tends to collect posterior to the heart, the anterior approach may result in a dry tap and, even more serious, injury to a coronary artery Also, in a small percentage of individuals there is no bare space to the left of the sternum, in which case the needle traverses the free pleura before entering the pericardium.

Left Parasternal Route

After local infiltration with 1 per cent procaine the needle is inserted through a knife puncture of the skin at a point 3 cm. lateral

20 per cent Whichever of the foregoing agents is used, the atomizer also should contain 1 cc of epinephrine 1 1000. The tongue is kept forward for a few minutes after spraying, the anesthetic agent, mixed with pharyngeal secretions will run down into the larynx. Spraying is repeated three times at intervals of three minutes

Anesthesia can be more easily and quickly attained by first spraying the throat, then, with the aid of a laryngeal mirror, swabbing the glottis and vocal cords two or three times with a curve-handled brush wet with the same pontocaine (or cocaine, metycaine or procaine) epinephrine solution.

A semirigid, red rubber tube, curved at an angle of 60 degrees and with one end beveled so that the long end of the slant lies on the concavity of the curve, finds its own way into the glottis if the tongue is held forward If there is any difficulty in introducing the tube it can be guided into the glottis with the left index finger Its introduction provokes cough, with each cough strong suction is made Aspirated vomitus, blood and secretions can be removed in this way, or an ordinary number 20 F rubber urethral catheter can be guided into the anesthetized larynx and used for suction

THORACENTESIS

Thoracentesis is ordinarily done only after x-ray films have been made, exceptions being emergency puncture for relief of pressure pneumothorax, and for removal of blood from the pleural cavity Thoracentesis is done for (a) diagnosis, (b) aspiration of contents of pleural cavity (air, serous effusion, blood, pus), (c) injection of air

Thoracentesis is not permissible in treatment of febrile, coughing men, especially those with foul, purulent sputum, unless good evidence exists (x-ray and physical signs) that considerable pleural fluid is present at the site of puncture To puncture the lung of a man who is coughing and expectorating foul sputum is dangerous and may cause empyema if it was not present before or, even more serious, a dissecting phlegmon of the thoracic wall Puncture is made with the man lying close to the edge of the bed or operating table With a fine (24 gauge) hypodermic needle, 1 per cent procaine is injected into the skin and intercostal space Exploration is done with a 19 or 18 gauge needle and a small syringe A large syringe impairs the tactile sense The needle is introduced at right angles to the thoracic wall and the plunger then is slightly withdrawn. With this precaution, and by moving the needle slowly and gently forward, it is possible to judge the depth of the layer of fluid If foul pus is obtained, the

usually at a depth of from 6 to 8 cm. The costoxiphoid route is recommended because there is little chance of contaminating the pleura and there are no large coronary arteries near the point of entrance into the pericardium (Figs. 2 and 3)

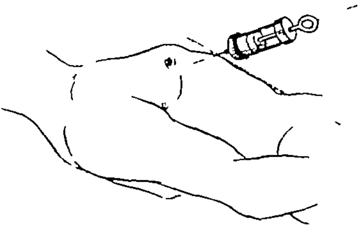

Fig. 3.—Pericardicentesis by the costoxiphoid route. The needle is inserted at an angle of approximately 45 degrees to the abdominal wall.

ARTIFICIAL PNEUMOTHORAX

Place the patient recumbent or on the sound side with the arm elevated, hand in back of head. If there is no special reason for choosing another site, infiltrate the skin and soft parts over the fifth or sixth intercostal space, in the midaxillary line, with 1 per cent procaine solution, using a fine hypodermic needle. Change to a 19 gauge needle and inject more procaine until the pleura has been penetrated. Remove the syringe, cover the needle with sterile gauze and allow a small amount of air to enter; then connect the needle to the manometer Wide fluctuation of the fluid in the manometer tube, with negative pressure readings on normal inspiration and expiration, indicates that the needle is in the pleural cavity Connect the needle to the pneumothorax apparatus and introduce 100 cc. of air; then check the manometer pressure and respiratory excursions. If the patient cannot lie on his good side because of respiratory distress, place him in the dorsal recumbent position and introduce air into the second or third intercostal space, 5 cm. lateral to the sternal border

If air is introduced to replace bloody exudate, 50 cc. of air may be injected with a hand syringe for each 50 cc. of fluid withdrawn, or preferably air is allowed to flow in through a needle inserted an-

to the left sternal border, just above the sixth costal cartilage Suction is applied and the needle is advanced cautiously until fluid is obtained, or until cardiac pulsations are detected against the point of the needle. If fluid is not obtained, the syringe is disconnected and a stilet is passed through the needle to be sure it is not plugged with tissue

Costoxiphoid Route

When the costoxiphoid route is used, a 10 cm needle is necessary. After local infiltration the needle is inserted in the angle be-

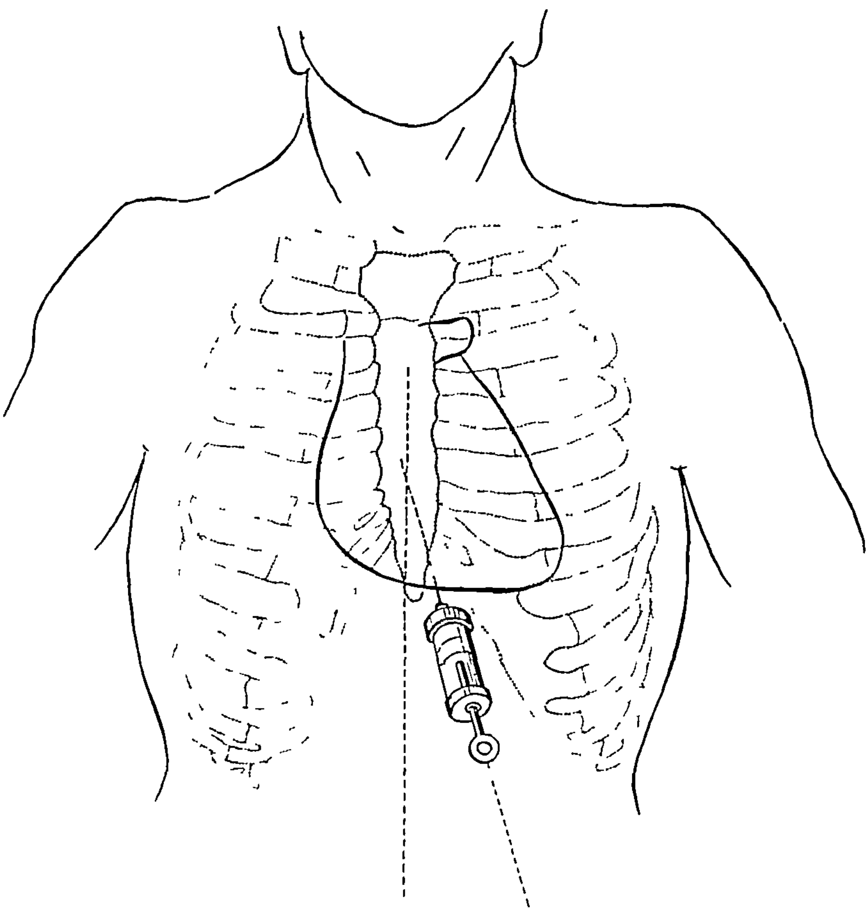

Fig 2—Pericardicentesis by the costoxiphoid route The needle is directed upward, backward, and very slightly to the right, to avoid the coronary vessels in the posterior longitudinal sulcus

tween the xiphoid process and the left costal margin and is passed upward and backward at an angle of 45 degrees to the abdominal wall The posterior inferior portion of the pericardial sac is entered,

into the chest it will not drain properly It is fixed in place by a suture which is passed through the edge of the wound, then through the side of the catheter or through a rubber collar made by cutting a short segment from the open end of the catheter It is also anchored by strips of flamed adhesive tape, but dependence should not be placed on adhesive tape alone. The parts of the apparatus repre-

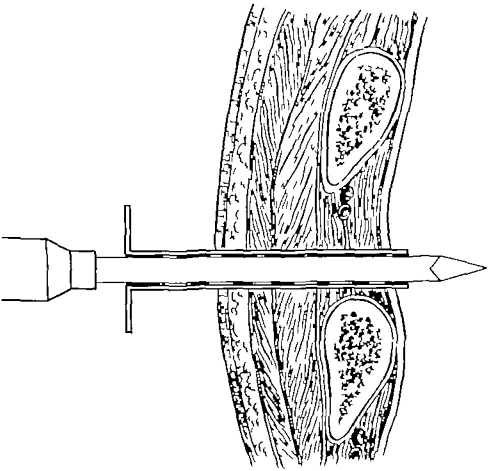

Fig. 4—Intercostal trocar-cannula-catheter drainage. Note that the trocar is inserted immediately above the rib margin in order to protect the intercostal vessels.

sented in Figure 6 should be snugly fitting so that the end of the tube which extends beneath the surface of the water does not hang loosely The apparatus, and the measured amount of water should be sterile. The occluding clamp on the catheter is then removed. The contents of the bottle which receives the drainage are saved for inspection and measured. The drainage tube is clamped while the contents of this bottle are being disposed of The bottle is placed on the

teriorly while the blood is aspirated through another needle inserted posterolaterally. The intrapleural pressure is checked and regulated before withdrawing the needle

CATHETER DRAINAGE (INTERCOSTAL DRAINAGE)

This may be done at the conclusion of thoracotomy, or as an independent procedure for evacuation of blood from a hemothorax, or for airtight drainage of an empyema cavity

Drainage at the End of Thoracotomy

In selecting a site for catheter drainage at the conclusion of thoracotomy, due allowance is made for the rise in the diaphragm that occurs in the postoperative period. The two sites for optimal drainage are the eighth intercostal space in the midscapular line and the fourth or fifth intercostal space in the anterior axillary line

A short incision in the skin allows a hemostat to pierce the intercostal muscles and grasp the butt end of the catheter that is presented through the major thoracotomy incision

Trocar-Catheter Drainage

The trocar and catheter are tested, the sheath must take the catheter easily If the end of the catheter flares it is cut off so that the sheath can be drawn over it. Aspiration by needle, to prove the presence of fluid at the site chosen for drainage immediately precedes insertion of a trocar The chest is ordinarily drained in the seventh or eighth interspace, in the posterior axillary line, if the site chosen lies too far back, the man will occlude the catheter by lying on it. The thoracic wall at the site of the puncture is anesthetized with procaine and incised with a pointed scalpel for a distance of 1 to 1 5 cm., so that it will not be necessary to use too great pressure in introducing the trocar and cannula. In order to avoid the intercostal vessels and nerves, the trocar is inserted across the upper border of a rib, not across the lower border (Fig 4) The trocar is withdrawn and a number 18 or 20 F catheter, with two eyes near the tip, is rapidly inserted through the cannula (Fig 5), which is then withdrawn The catheter is kept closed by a clamp during the procedure A mark is made on the catheter before it is inserted, so that the distance which it projects into the pleural cavity can be determined. The catheter can then be adjusted so that the most proximal opening is near the pleural surface If the catheter projects too far

ceases to escape then it is opened at intervals of from one to two hours for further drainage The catheter is removed at the end of six hours. When used for treatment of empyema, the catheter is not removed until the lung has become completely reexpanded and the empyema cavity has been obliterated.

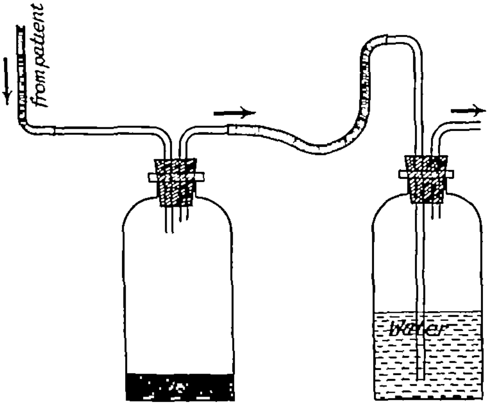

Fig. 6.—Two-bottle set for closed drainage of the pleural cavity

ELEVATION OF CAVED IN (CRUSHED) RIB CAGE

With Towel Clips

When a mechanical respirator is unavailable, this or a similar procedure may be indicated. Infiltrate the skin and soft parts with 1 per cent solution of procaine above and below the third and fifth ribs, 3 cm. lateral to the sternal border Small incisions are made in the skin and an open towel clip is applied so that the costal cartilage is grasped between its jaws one clip is placed around the third and one around the fifth cartilage. Attach the towel clips by wire or heavy cord to 5 pound (about 2.5 kg.) weights, running the cord or wire over a pulley suspended from an overhead frame, or use short handled clips and attach them to a plaster jacket by rubber bands.

floor beside the bed and must at no time be raised to the level of the bed Sufficient difference in level is thus maintained to make it impossible for the patient to aspirate the contents of the bottle back into the chest, even by the deepest inspiration

When used for evacuation of sterile hemothorax, this method has the advantage of not forcibly expanding the lung (as aspiration with a large syringe or Potain apparatus does), and inviting a recurrence

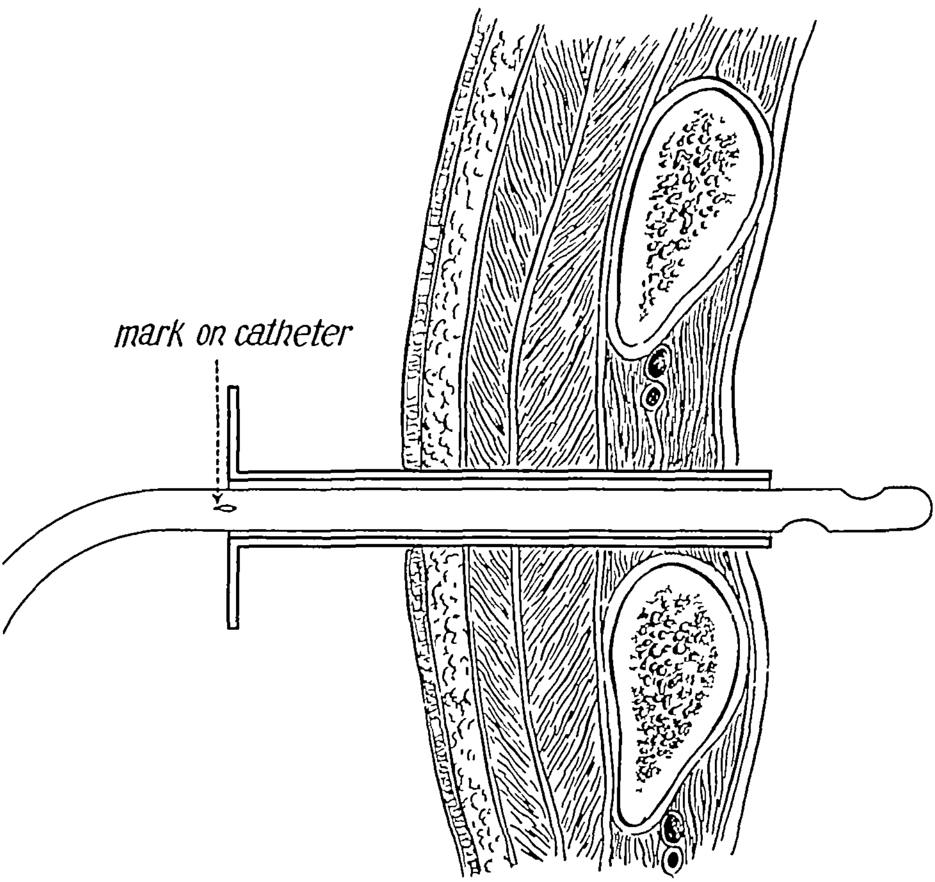

Fig 5—Intercostal trocar-cannula-catheter drainage The mark on the catheter is used to determine the distance which the catheter projects into the pleural cavity

of hemorrhage, yet it drains the chest more nearly completely and continuously than aspiration by needle Excluding air from the chest decreases the chance of secondary infection If, however, reexpansion of the lung is likely to cause recurrence of bleeding, air may be allowed to enter as the fluid escapes by allowing the tube to hang free in the container above the surface of the sterile water When the latter procedure is used, the tube is clamped shortly after the fluid

another incision in the skin. If available it will be safer to use an aneurysm needle. The empty needle is passed around the rib or car tilage, then threaded with the wire and withdrawn. One wire is passed around the third and one around the fifth cartilage. Twist or tie each pair of wires around a spreader made of three tongue blades fastened together with adhesive tape attach a cord or wire to the spreader and use a 5 pound (about 2.5 kg.) weight for traction applied over a pulley suspended from an overhead frame (Fig. 7) or attach the wire to a plaster jacket.

A mechanical respirator if available, may be of great assistance in the management of patients with extensive mobilization of the thoracic wall.

LIGATION OF AN INTERCOSTAL ARTERY

In choosing the site of incision, account will be taken of the course of the projectile more frequently bleeding will occur at the

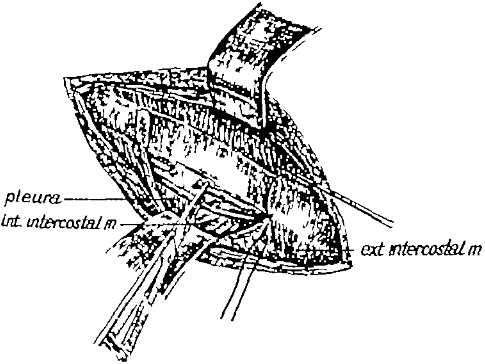

Fig. 8.—Control of hemorrhage from a posterior intercostal artery by rib resection and ligation of the injured vessel or by application of a pericostal suture ligature.

point of entry into the chest, less frequently at the exit hemorrhage is more likely to be serious from wounds of the posterior portions of the intercostal arteries than from the anterior portions.

If a plaster jacket is used it must be padded so that at least 6 inches (15 cm) separate it from the anterior thoracic wall

With Pericostal Sutures

Anesthetize the soft parts adjacent to the ribs as described in the preceding paragraph Make small incisions in the skin at least

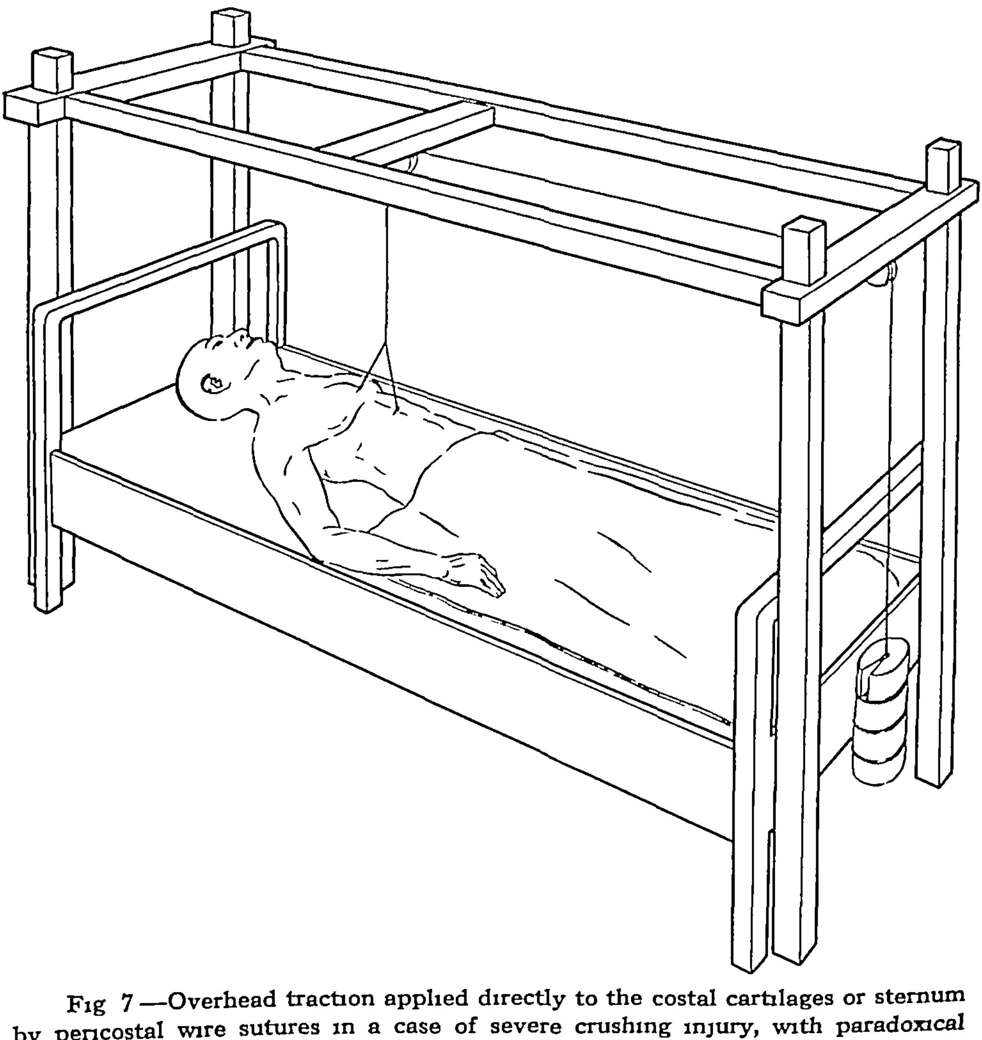

Fig 7—Overhead traction applied directly to the costal cartilages or sternum by pericostal wire sutures in a case of severe crushing injury, with paradoxical respiration. If it is necessary to transport the patient, the wires can be attached to a plaster cast by rubber bands The weights shown in the drawing represent 5 pounds (about 2 5 kg) The spreader mentioned in the text is not shown

3 cm from the sternal border and introduce a heavy, full curved needle armed with 12 inches (30 5 cm) of heavy, stainless steel or silver wire Pass the needle around the costal cartilage, keeping the point of the needle close to the cartilage, then bring it out through

another incision in the skin. If available it will be safer to use an aneurysm needle. The empty needle is passed around the rib or cartilage, then threaded with the wire and withdrawn. One wire is passed around the third and one around the fifth cartilage. Twist or tie each pair of wires around a spreader made of three tongue blades fastened together with adhesive tape attach a cord or wire to the spreader and use a 5 pound (about 2.5 kg.) weight for traction applied over a pulley suspended from an overhead frame (Fig. 7), or attach the wire to a plaster jacket.

A mechanical respirator if available, may be of great assistance in the management of patients with extensive mobilization of the thoracic wall.

LIGATION OF AN INTERCOSTAL ARTERY

In choosing the site of incision, account will be taken of the course of the projectile more frequently bleeding will occur at the

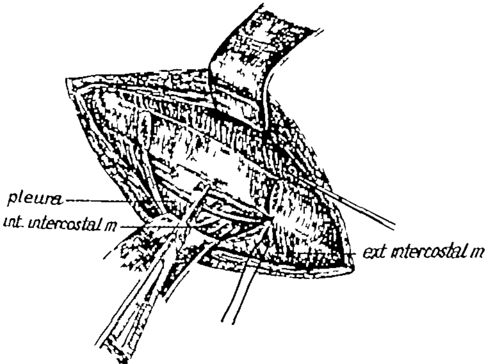

Fig. 8.—Control of hemorrhage from a posterior intercostal artery by rib resection and ligation of the injured vessel or by application of a pericostal suture ligature.

point of entry into the chest, less frequently at the exit; hemorrhage is more likely to be serious from wounds of the posterior portions of the intercostal arteries than from the anterior portions.

Débridement is performed through an adequate incision The vessel lies for the most part beneath the lower edge of the rib, therefore, if it cannot otherwise be satisfactorily exposed, 2 to 3 cm of the rib is resected (Fig 8)

PERICOSTAL SUTURE FOR HEMORRHAGE FROM INTERCOSTAL ARTERY

Under especially urgent circumstances, or when facilities for rib resection are not at hand, hemorrhage from an intercostal vessel can be controlled by encircling the rib with two ligatures of catgut; one proximal, the other distal to the site of injury Nonabsorbable suture material should not be used Compression of the artery between the ligature and the rib will usually control hemorrhage (Fig 8)

LIGATION OF THE INTERNAL MAMMARY ARTERY

An incision is made over a cartilage adjacent to the wound, extending from the sternal border laterally for a distance of 6 or 7 cm

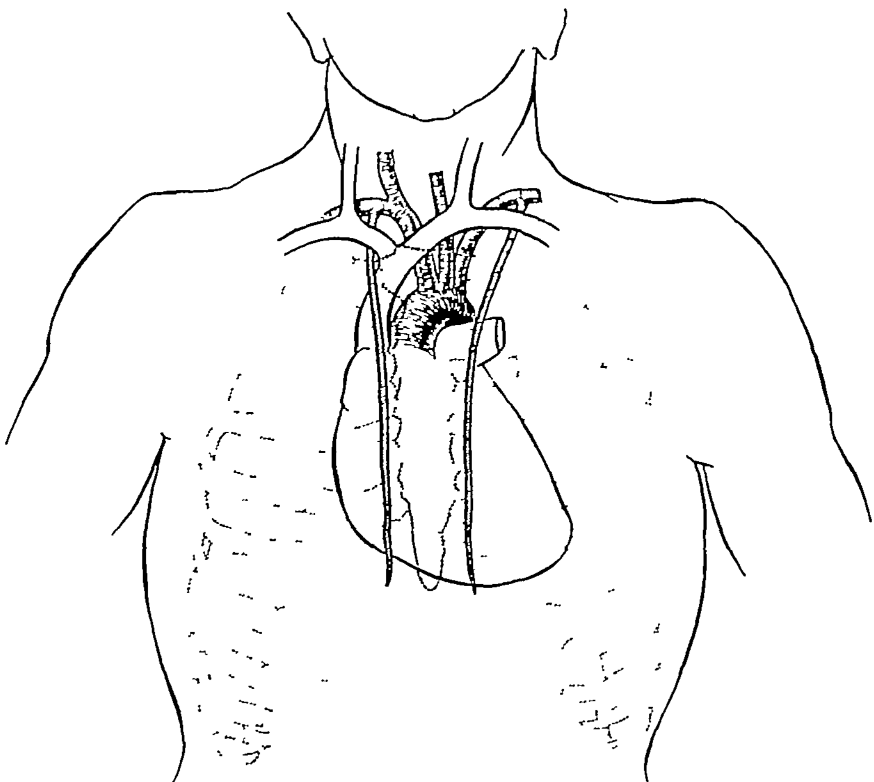

Fig 9—The relation of the internal mammary arteries to the sternum The position of the heart and great vessels of the mediastinum, in the anteroposterior direction, are also shown.

About 3 to 4 cm. of the medial end of the cartilage is excised, thus exposing the internal mammary vessels lying about 1 cm. lateral to the sternal border They are ligated above and below the site of injury for owing to its anastomosis with the inferior epigastric artery and the lower intercostal arteries, both ends of a mammary artery bleed freely A suction tip then can be inserted through the opening in the pleura and the blood aspirated. Some of the relations of the artery are represented in Figure 9

RIB RESECTION AND DRAINAGE FOR EMPYEMA OF PLEURA

Rib Resection and Drainage with a Rubber Tube

The site must depend on localization of the pus and confirmatory thoracentesis is performed as the first step. Solution of procaine, 1 per cent, is injected into the skin and soft tissues overlying the rib and the skin is incised for about 8 to 10 cm. The muscles and inter

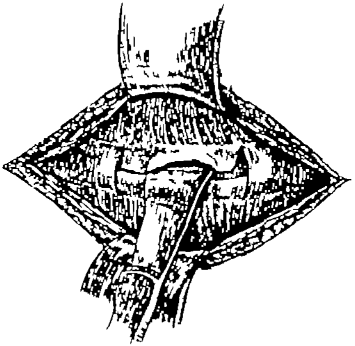

Fig. 10—Elevation of the periosteum preliminary to rib resection.

costal spaces above and below the rib are then infiltrated with the anesthetic solution and the muscles are divided throughout the extent of the skin incision. The external periosteum is incised longitudinally then transversely at each end, and separated from the rib by a raspatory (Fig. 10) The upper border is cleaned by working

from behind forward, the lower border in the reverse direction The internal periosteum is separated from the rib by a curved elevator and the rib divided by rib shears Unless all of the rib from which the periosteum has been separated is resected, sequestra may form and cause prolonged drainage The internal periosteum and parietal pleura are incised in line with the long axis of the rib and a soft rubber drainage tube of large caliber is inserted The end of the tube is beveled and a window is cut opposite the bevel A safety pin is passed through the tube at such a distance as to place the window only a short distance within the pleural cavity The tube is securely anchored by suturing it to one edge of the incision (Fig 11)

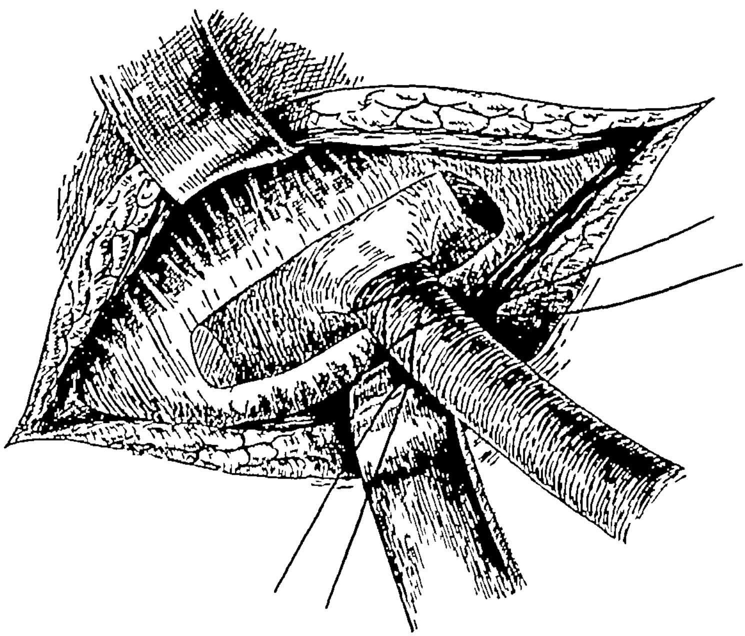

Fig 11—Method of obtaining temporary closed (water-sealed) drainage of the pleural cavity after rib resection Note that the internal periosteum and pleura are closed snugly around the tube and that the tube is firmly fixed in place by crossing the ends of the sutures around it.

Small empyema cavities, with strong adhesions between lung and thoracic wall, may be completely evacuated of their contents on the operating table Open drainage of larger cavities, however, in spite of the encapsulation, may produce a sucking wound that leads to respiratory embarrassment. To avoid this complication, and also to reduce the number of postoperative dressings, to economize on gauze and to minimize the contamination of bed linen, it is recommended that the free end of the tube be connected with a long, sterile tube of equal caliber and carried over the edge of the bed to a water-seal bottle, as is employed for airtight catheter drainage

Rib Resection and Drainage with a Skin Flap

This method has proved especially valuable under war conditions. Once established, it demands no further attention, there are no tubes to drop out or, worse to drop into the chest and be forgotten. If the operation is properly done the incision will not close until the lung has expanded to meet it.

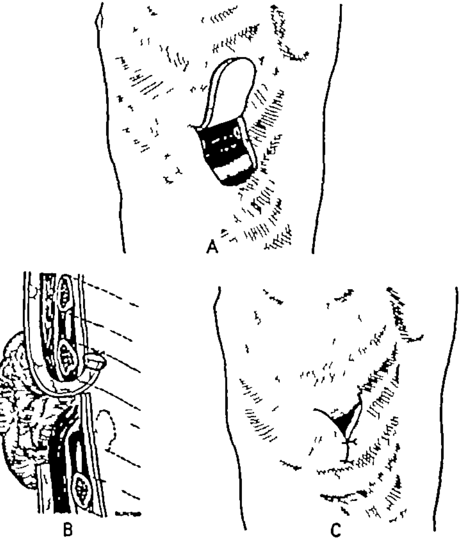

Fig. 12.—A, B, and C, Successive steps in the operation to provide drainage of an empyema cavity by making of a skin flap.

With the man seated across the table, or semireclining, a U shaped flap of skin and subcutis is outlined. Its base is 1¾ to 2 inches (about 4.5 to 5 cm.) wide and lies along the line of the rib to be resected, usually the eighth, resection is in the posterior axillary

line The sides of the flap are 2 or 3 inches (about 5 or 7 5 cm.) long, shorter for thin men, longer for fat ones Procaine is injected into the skin and subcutis, the flap is cut and lifted with a towel clip (Fig 12, A). The flap includes skin and subcutis only—not the muscle. Two sutures of chromic gut are put through its corners, each armed with a small curved needle with a cutting edge Procaine is injected into the soft parts and intercostal spaces and 2 inches (about 5 cm) of rib are resected, as described in the preceding paragraph The pleura is incised The chromic sutures of the flap are passed through the pleura By tying them the skin flap is tucked into the chest and held against the pleura (Fig 12, B) The corners of the U-shaped defect in the skin are approximated with sutures so that the U is converted into a narrow, transverse slit (Fig 12, C) A dressing of a large mass of vaseline, some 30 to 50 cc, is laid over the wound and held in place by a bandage The outer dressing may be changed but the inner one remains for four to five days The flap acts as a valve The contents of the chest escape, it is difficult for air to enter and the lung expands rapidly Should the flap swell at first, it may be lifted with a tongue blade every day or two, in order to let the contents of the empyema cavity escape After a few dressings the discharge becomes serous and rapidly diminishes in amount. When the lung has expanded it meets the tip of the flap and the wound is converted into a small funnel in the soft parts of the chest.

THORACOTOMY FOR PENETRATING WOUNDS

Anesthesia (see Chapter I, "Anesthesia" [p 222])

While operations of short duration can be performed without differential pressure anesthesia under emergency conditions, the forceful movements of the mediastinum, combined with progressive asphyxia, offer a serious handicap to the surgeon Differential pressure is requisite for accurate appraisal of the injury and an operation of precision It can be obtained by a tightly fitting face mask or, preferably, by an intratracheal tube The advantage of tracheal intubation lies in (1) the impossibility of the patient making violent respiratory efforts against a closed glottis, (2) the certainty that a stream of oxygen will reach the lung during periods of cessation of respiration, (3) the maintenance of a free air-way by aspiration of blood and mucus. The statement that tracheal intubation is to be avoided because it causes contamination of the lower air passages may be discounted.

Procaine block of intercostal nerves and subpleural perihilar

infiltration with procaine contribute to smooth anesthesia and block the cough reflex.

Incision

Wounds of entrance and exit are excised and fragments of ribs and other foreign bodies are removed. Deep structures are approximated to give airtight closure of the pleural cavity The superficial portion of a wound is packed open following local application of a sulfonamide. Gauze used for packing is anchored to the skin margin to prevent retraction into the pleural cavity

A separate site is chosen for the thoracotomy incision unless the injury of the thoracic wall is so extensive and so placed that ample exposure for the necessary intrathoracic procedures is obtained at the time of débridement of the thoracic wall.

Incisions for exposure of the lung are placed parallel with the course of the ribs and are either *anterolateral* or *posterolateral* The choice depends on the region for which most direct exposure is desirable and, to some extent, on the condition of the patient. Which ever incision is elected, its length and proper placement determine the exposure that is obtained more than this is determined by the number of ribs resected or divided. Division of ribs is kept at a minimum in order to avoid undue crippling of respiratory movements in the postoperative period. The so-called trapdoor incision still pictured in textbooks is not recommended as it affords minimal exposure with maximal damage to the thoracic wall.

Anterolateral Incision.—An anterolateral approach is useful for lesions involving the upper lobe of the lung or the superior mediastinum. It affords a direct approach to the superior pulmonary vein and to the pulmonary artery

The patient is placed in the dorsal recumbent position, with the wounded side sufficiently elevated to allow the incision to be extended to the posterior axillary line. This position itself may be so advantageous to patients with labored respiration, or with injuries to the opposite side of the thorax, that this will determine use of the anterior approach.

The incision is placed at the level of the third interspace and extends laterally from the margin of the sternum to the midaxillary line. The axillary border of the pectoralis major muscle is identified and retracted upward and medially To reach the costal cartilage the lower portion of the muscle is divided transversely Digitations of the serratus anterior muscle are separated in the direction of their fibers in exposure of an interspace low in the axilla. Extension of

the incision to require division of the long thoracic nerve is rarely necessary

The intercostal muscles of the third interspace are divided and the pleura is incised Additional exposure can be obtained by dividing one or both adjacent costal cartilages

Posterolateral Incision—A posterolateral incision is best for exposure of the lower lobe of the lung and the posterior mediastinum It affords direct access to the inferior pulmonary vein and the stem bronchus By retracting the upper lobe downward and backward, the pulmonary artery and superior pulmonary vein are readily accessible Total pneumonectomy can be performed through either this or the anterolateral incision The patient is placed on his sound side, with a blanket roll extending from the axilla to the costal margin. Care must be taken to avoid weight bearing on the point of the shoulder which is down Strapping is employed to anchor the patient firmly in a true lateral position, as difficulty will be encountered if he tends to rotate forward on his face The arm is extended upward.

The incision follows the line of the sixth rib, curving beneath the inferior angle of the scapula It starts 2 inches (about 5 cm) from the spinous process of the vertebra and extends to the anterior axillary line The latissimus dorsi muscle is divided transversely, as is the lower segment of the serratus anterior, that finds its insertion in the lower angle of the scapula Lower fibers of the rhomboid and trapezius are divided near the spinal column

After the ribs have been exposed, a check is made to identify the sixth In counting from below it is helpful to refer to the x-ray film to determine whether a palpable twelfth rib is present

The erector spinae muscle group is mobilized by dividing tendinous insertions on the fifth, sixth and seventh ribs This muscle is not divided transversely but retracted toward the midline, so that it will be available in closure.

Subperiosteal resection of the sixth rib is then carried out from the level of the transverse process of the vertebra to the midaxillary line The posterior layer of periosteum and pleura is incised to gain access to the pleural cavity For greater exposure, the incision can be carried forward by extending it in the intercostal space above the divided rib Further exposure, posteriorly, can be obtained by resecting 1 inch (about 2 5 cm) segments of adjacent ribs just posterior to the angles Intercostal muscle bundles, nerves and arteries are divided.

The posterolateral incision can be carried through an intercostal space without rib resection Rib resection is recommended not only

for exposure but for greater accuracy of pleural approximation in closure.

Closure of Incision.—An intercostal incision is closed by heavy pericostal sutures, as the divided intercostal muscles do not provide firm anchorage A posterolateral incision, with rib resection, is closed by suture of pleura periosteum and intercostal muscles in the bed of the rib. The erector spinae muscle bundle is then brought forward and sutured to intercostal muscles.

Forceful approximation of the incision is necessary during suture. If a special instrument is not available two sharp-clawed retractors are used to grasp adjacent ribs and pull them together A bone-holding forceps with ratchet lock can be adapted to this purpose.

The divided muscles of the thoracic wall are accurately sutured with attention to the axis of their fibers. The oblique course, particularly of the latissimus dorsi, produces irregular retraction of the divided muscle bundles.

Traumatic Lesions of Lung

As the retractor is spread, the anesthetist adjusts the differential pressure so that the lung does not bulge into the incision but falls somewhat away from the thoracic wall. The pleural cavity is emptied of blood, clots are removed with the hand or forceps. Active bleeding from the hilar region is immediately controlled by manual compression until a hemostat can be placed with precision, or a hemostatic suture can be accurately placed without damage to neighboring structures.

Normal lung inflates and deflates as the anesthetist varies the intratracheal pressure by compressing the gas bag of the anesthesia apparatus. An atelectatic portion of lung is contracted, flaccid, deep red and has sharp margins. Contused lung (hematoma) appears plump, firm, and the margins of the fissures are rounded due to distention with alveolar blood.

Lung tissue is fragile and easily torn it should not be grasped by forceps, but gently displaced by the hand with aid of moist gauze. Further reduction in positive pressure is an aid to exploration but, as this is done, a note is made of portions that were atelectatic when the chest was opened in contrast to portions that were inflated but become collapsed in the course of operation. The latter are reinflated from time to time during the operation and are left inflated when the chest is closed. Efforts should not be made forcibly to inflate lung that was found atelectatic when the chest was opened.

As the injury to the lung is disclosed, careful appraisal of its

nature is possible Pieces of clothing, fragments of bone and other foreign bodies are removed Active bleeding from a deeply lacerated lung can be controlled by a hilar tourniquet or by manual pressure at the hilum, such control permits excision of devitalized fragments and hemostatic suture or resection (Fig 13)

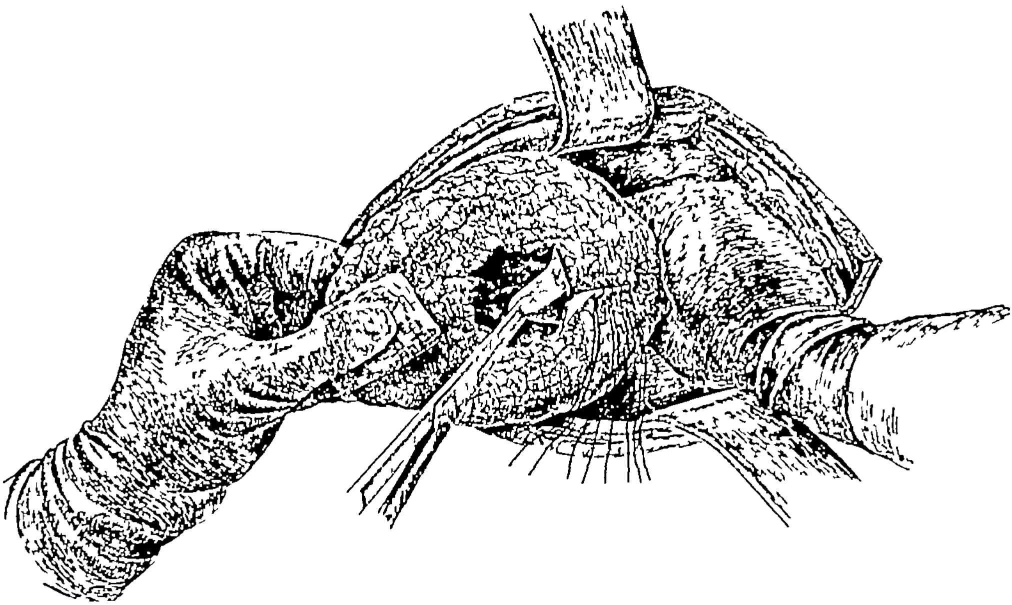

Fig 13—Excision of devitalized pulmonary tissue Control of hemorrhage by manual compression of hilum of lobe

Hematoma of the lung, or atelectasis, is not an indication for resection, as spontaneous repair will take place Large hematomas may result from penetration of tiny foreign bodies and, even if the foreign bodies remain embedded in the lung, no attempt should be made to remove them

Resection of Irreparably Damaged Lung

Débridement and suture will be adequate for the majority of patients who reach a hospital where operation can be performed In a few cases lobectomy or pneumonectomy may be required for deep laceration, particularly near the hilum, or for such extensive destruction that there is real doubt as to future functional value It is repeated for emphasis, however, that atelectasis and hematoma are not in themselves indications for resection

Débridement and Suture of Lacerated Lung—Lacerated lung is grasped with the aid of gauze, and traction sutures are inserted to aid in holding it in an accessible position Devitalized tissue is excised

and the bleeding surface is approximated with continuous or interrupted sutures of plain No. 0 catgut. It is best to cut, suture and then cut again rather than to complete the excision and be faced with a bleeding, retracted lung. Large, bleeding vessels can be identified and individually ligated. Open bronchi are ligated or sutured.

Lobectomy—This is most easily and quickly performed if a tourniquet is employed although, if the surgeon is familiar with the complexities of intrahilar anatomy he may use his judgment in employing the precise technics required for ligation of individual vessels and bronchi. There is much less danger of a subsequent bronchial fistula if instead of using a tourniquet and mass ligation of the hilar structures, the bronchus is dissected out and sutured carefully with silk or with fine, stainless steel wire.

Incomplete lobar fissures prevent proper application of a tourniquet about the hilum of a lobe. Incomplete fissures are commonly found between the right upper and middle lobes, and between the apex of the lower lobe and the adjacent part of the corresponding upper lobe. They may occur elsewhere. To complete a fissure for application of a hilar tourniquet, lung parenchyma is grasped with hemostatic clamps parallel placed, and then the tissue is divided. The clamps are enveloped with a continuous suture the clamps are then removed and the suture is set.

Mobilization of a lower lobe for application of a tourniquet requires division of the pulmonary ligament—a reflection of mediastinal pleura that forms a "mesentery" extending from the diaphragm to the hilum (Fig. 14) Vessels that require ligation may occur in the pulmonary ligament. The inferior pulmonary vein is situated at its upper end and care is taken not to wound it.

Adhesions between parietal wall or mediastinum and the lung also require section before a tourniquet can be applied. Contained vessels are ligated.

After complete mobilization of a lobe, the hilar tourniquet is employed to occlude bronchi and vessels while the lobe is amputated and hemostatic sutures are being placed. A generous stump (1 inch or about 2.5 cm.) is left distal to the cord of the tourniquet to forestall retraction and permit firm suturing.

Sutures of chromic catgut (No. 1) are placed in the conglomerate mass of bronchi and blood vessels that present in the center of the amputated stump. Some of these are cut long and serve for traction to replace hemostatic clamps that are applied for this purpose during the actual amputation. After sutures have been placed to occlude the vessels and bronchi of the stump, the tourniquet is released but

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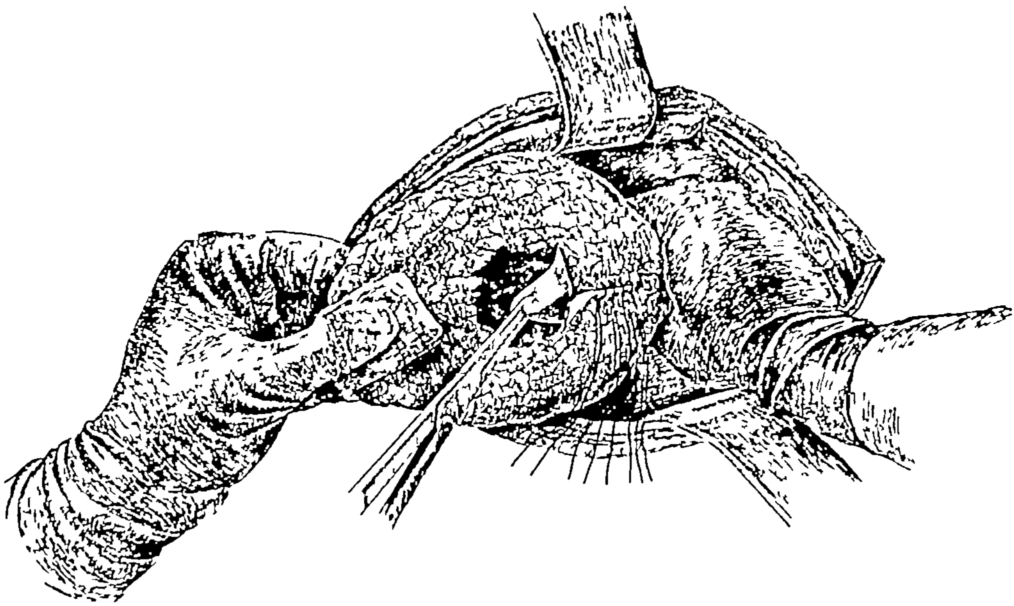

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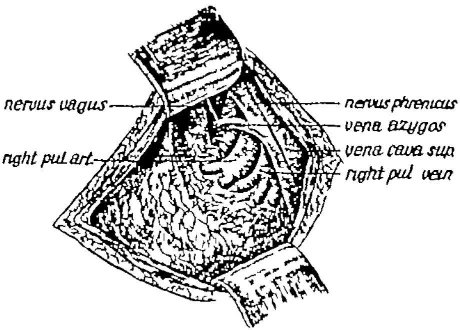


Fig. 15.—The relationship of important structures in, and immediately adjacent to, the hilum of the right lung

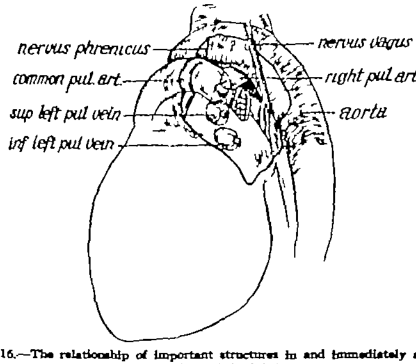


Fig. 16.—The relationship of important structures in and immediately adjacent to the hilum of the left lung.

it is for lobectomy A circular incision of mediastinal pleura is carried about the hilum at the line of its reflection onto the root of the

is left in place so that it can be tightened again if further sutures are required When the tourniquet can be removed completely, without further hemorrhage, the cuff of lung that surrounds the stump is sutured over the deeper structures

Total Pneumonectomy—An entire lung may be resected for uncontrollable hilar bleeding or extensive laceration by a technic

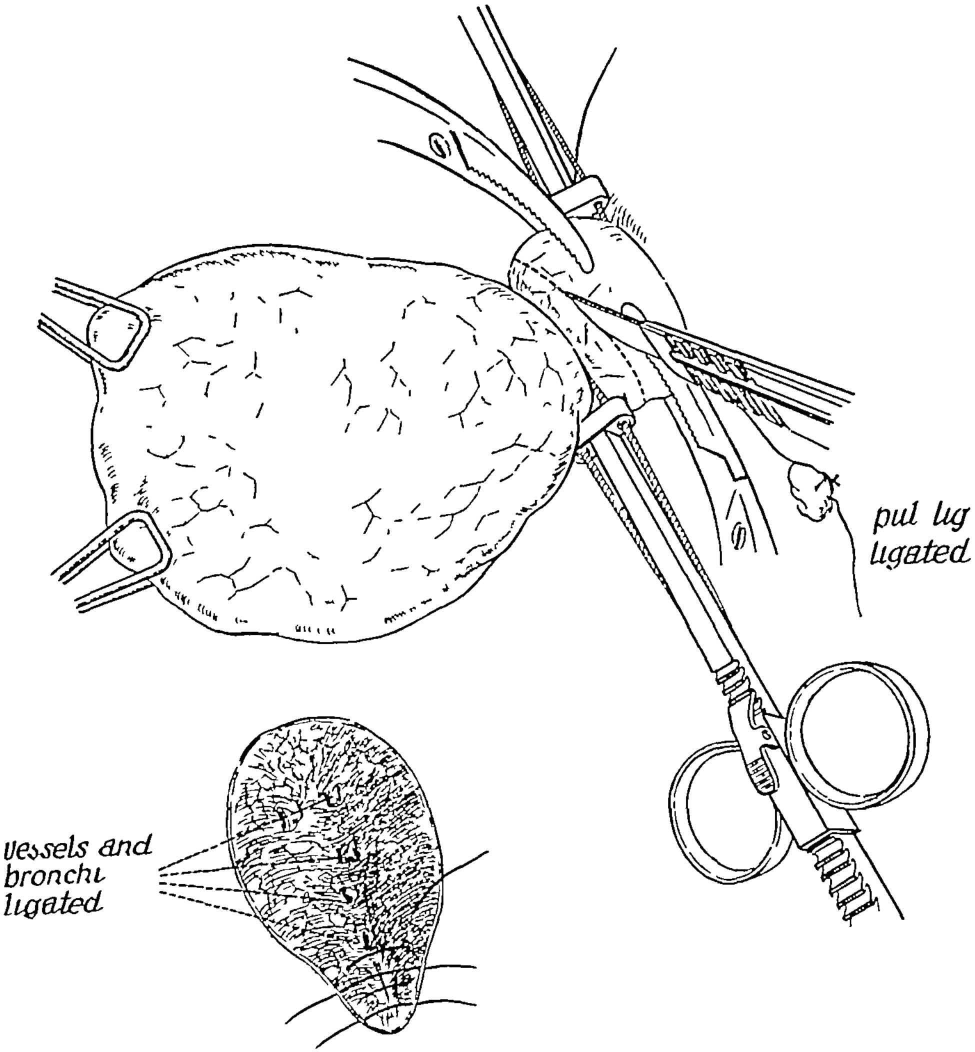


Fig 14—Tourniquet technic for lobectomy

similar to that just described After division of the pulmonary ligament and any parietal or mediastinal adhesions, the tourniquet is set about the hilum Amputation and closure of the stump are performed as in lobectomy.

For total pneumonectomy the procedure of individual ligation of vessels and accurate closure of the bronchus is more desirable than

If the lung is adherent, all of the denuded parts of the ribs are resected and the intercostal structures and periosteum are removed. The lung is then palpated through the pleura and a large aspirating needle is inserted in the center of the indurated portion. When the cavity has been entered and pus or foul air is withdrawn, the needle is allowed to remain and, with it as a guide, the abscess is opened. The opening is best made with a cautery The contents of the cavity are evacuated by suction. Oxygen or air administered under pressure by a tightly fitting mask, will aid in expelling the contents of the cavity The abscess is packed with a long strip of gauze, which is also used to fill the incision. The margins of the wound and this packing may be left undisturbed as long as there is no evidence of pus being retained behind it (purulent expectoration) It may be necessary to repack for secondary hemorrhage.

A well localized superficial abscess may be drained by raising a skin flap, as is described under empyema (page 271) This method is especially advantageous when the man is subject to distant evacuation and repeated transfer from the care of one medical officer to another

REMOVAL OF FOREIGN BODY FROM THE LUNG

See Chapter III, "Foreign Bodies" (p. 248) and Chapter IV "Thoracotomy for Penetrating Wounds" (p. 272)

Early Removal at Thoracotomy

Palpation of the lung for a foreign body is best made with temporary reduction of the positive pressure anesthesia. When the foreign body has been felt, the lung containing it is grasped between the thumb and finger an incision is made onto the foreign body the body is extracted and the incision is repaired with a few deep sutures of plain catgut. The grasp on the lung is not released until all of these maneuvers have been completed.

Late or Delayed Removal in Presence of Infection

Operation is carried out as for two-stage drainage of a lung abscess. After rib resection, the foreign body is localized by thrusting two long hatpins down to it, under fluoroscopic guidance one passes through the region of the rib resection and the other through the intact thoracic wall in a plane perpendicular to that of the first pin. An opening is made down to the foreign body by following along the first pin with a galvanocautery or an endotherm. A sponge forceps

injury, it may be expedient to suture the lung to the thoracic wall instead of resecting it and closing the chest The lung is grasped and drawn into the incision. It is transfixed with a pair of deep, catgut, stay sutures and the lacerated pulmonary tissue between them is cut away Additional sutures are placed, if necessary, to secure a firm hold, but they are not tied until they are passed through the pleura and soft parts of the thoracic wall They are then tied so that they hold the lung up firmly against the opening in the thoracic wall Gauze is packed against the lacerated lung and the skin and soft parts of the chest are sutured loosely around the gauze A firm dressing is applied This operation has the advantage that suppuration occurring in the lung will find its way out of the thorax instead of into it. Dependent, closed intercostal drainage of the pleural cavity is also provided

SURGICAL DRAINAGE OF LUNG ABSCESS

The lung abscess is carefully localized by x-ray It is generally wise to have the patient in a "head down" position in order to get the benefit of gravity in drainage and to minimize the danger of the entrance of pus into unaffected parts of the lung The incision is over the region in which the abscess most nearly approaches the thoracic wall This is important for two reasons. first, the lung is almost always adherent in this region, second, in removing the roof of the abscess cavity, only a thin layer of pulmonary tissue will be excised The incision may be horizontal, perpendicular or curved, in the upper part of the axilla and in the area between the scapula and the spinal column, perpendicular or hockey-stick incisions have advantages, in other areas, especially anteriorly, more horizontal ones are preferable

A wide area is exposed to permit the entire external surface (roof) of the cavity to be removed, usually two ribs are exposed, but anteriorly one rib often suffices. The periosteum is carefully separated from the rib or ribs, as the case may be, and the intercostal muscles are excised to determine whether or not the two layers of pleura are adherent. If they are not adherent, the mottled lung can be seen moving with respiration through the thin parietal pleura If there is any doubt as to fixation of the lung to the parietal pleura, the denuded ribs are not resected but gauze packing is inserted between them and the pleura, and the fascia and skin are loosely approximated by interrupted sutures A week or ten days later the second stage of the operation may be done

sixth rib to the nipple line or slightly beyond (Fig. 17) The skin-fascia-muscle flap is turned up to expose the third, fourth, and fifth costal cartilages and the anterior ends of the corresponding ribs. In injuries near the apical portion of the heart, the fourth and fifth cartilages and the anterior ends of the corresponding ribs are resected subperiosteally If there is doubt as to the level of the wound in the heart, the approach is better too high than too low, as the cardiac apex can be elevated by using an apical suture but the base of the heart cannot be appreciably depressed (Fig. 18) The perios-

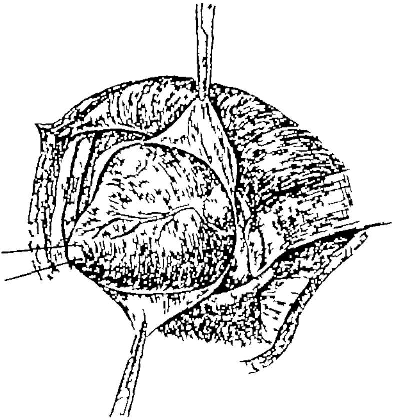


Fig. 18.—The apical traction suture (Beck) being used to expose a postero-lateral wound of the heart.

teum and intercostal bundles are divided near the sternum and retracted, to expose the internal mammary vessels which are ligated proximally and distally and resected between the ligatures, the communicating intercostal vessels also are ligated.

The loose tissue anterior to the pericardium is incised perpendicularly near the sternal border and stripped laterally with the pleura. It is essential that satisfactory exposure be obtained before the pericardium is opened in cases of tamponade therefore, if the position

is introduced into the channel, the body then is grasped and extracted. The channel is packed with gauze and the wound is left open A sponge stick makes a much better extractor than a hemostat. Much time, trouble and laceration of the lung will be saved if this act of grasping the foreign body is done under fluoroscopic control

If extensive fibrosis and chronic suppuration surround a deeply seated foreign body, lobectomy is preferable

CARDIORRHAPHY

It should be remembered that double wounds of the heart, one of entrance and one of exit, are not uncommon and that if a wound of the anterior surface is found, inspection of the back of the heart should not be omitted

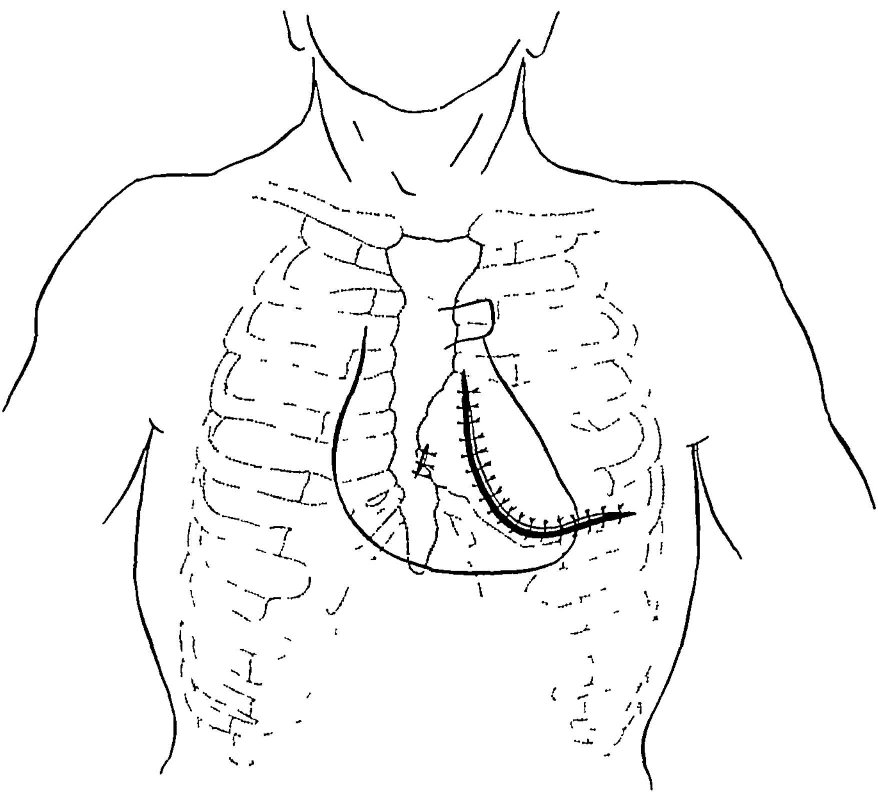


Fig 17—Incision for extrapleural exposure of the heart. A portion of the sternum has been rongeured away This may sometimes be avoided by the use of an apical traction suture (see Fig 18)

Extrapleural Approach

The level of the incision depends on the apparent location of the wound. Generally it is placed along the left costal margin, from the second interspace to the sixth rib and along the lower border of the

cardiac wound is anterior and well exposed, it is covered by the tip of the index finger of the left hand while a deep suture of silk is passed beneath the finger at a right angle to the wound (Fig. 19) This suture is then used as a traction suture to steady the field and also partially to close the wound while interrupted, approximating sutures are placed and tied. The traction suture may then be removed unless it is certain that it has not penetrated the endocardium. If the wound in the heart is lateral or posterior or for any reason is difficult to expose an apical traction suture is inserted in the tip

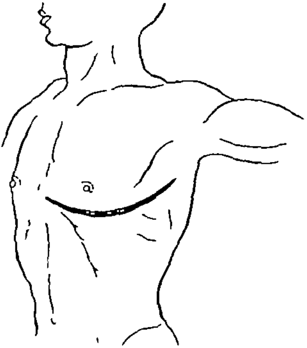


Fig. 20 —Incision in fourth intercostal space for transpleural exposure of the heart.

of the left ventricle and the wound is repaired as just described (Fig. 18)

When repair has been completed, the pericardial cavity is thoroughly flushed out with warm, physiologic saline solution, care being taken to remove all blood clot. The pericardium is loosely approximated by interrupted sutures and the incision in the thoracic wall is approximated with interrupted fine silk sutures for the pectoral sheath and the skin. Drainage material is not used.

Transpleural Approach

When there is associated pleural or pulmonary injury or when there is great urgency the heart is exposed by a long intercostal

of the wound causes any doubt, another cartilage is divided near the sternum or resected In the presence of tamponade from hemorrhage,

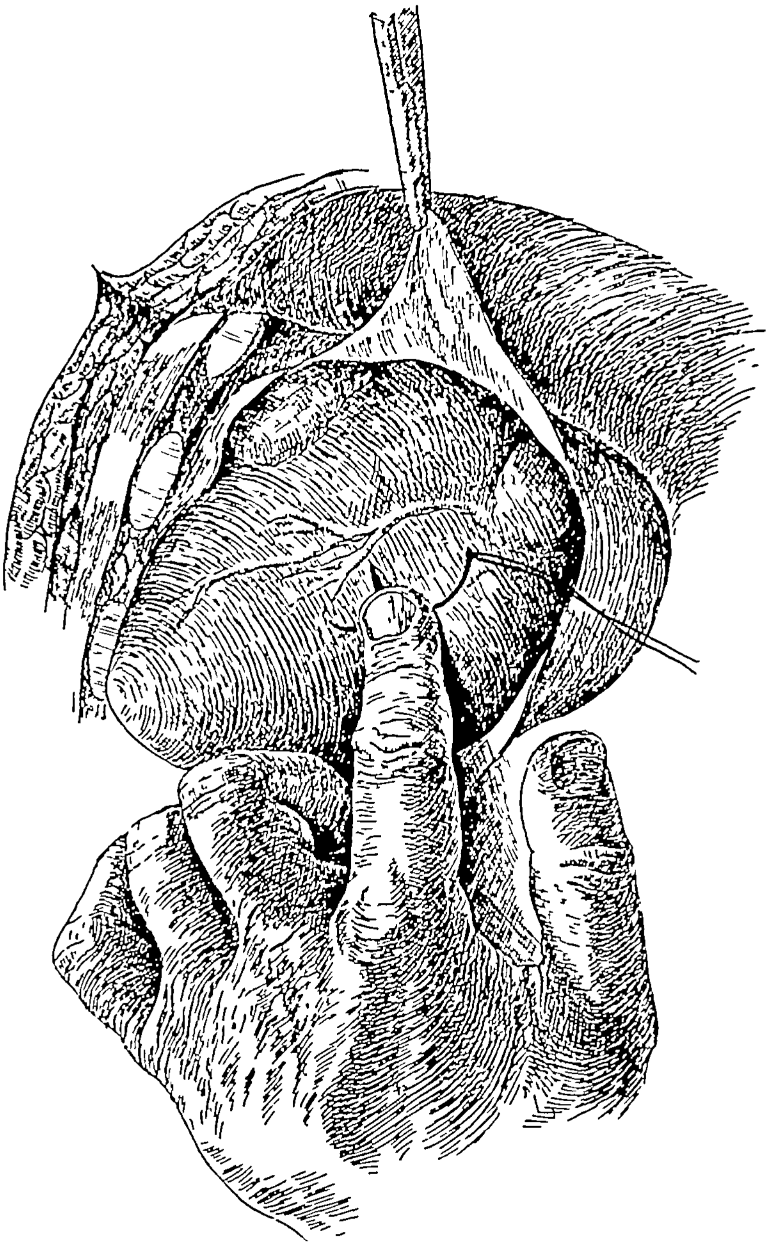


Fig 19—Cardiorrhaphy The wound is covered by the left index finger while a deep suture is inserted This suture is used to steady the field and also partly to close the wound while the approximating sutures are inserted and tied The original suture should then be removed if it seems likely that it has penetrated the endocardium.

the pericardium will be dark and tense It is carefully but adequately incised and liquid blood promptly is removed by suction If the

and at frequent intervals in the course of manipulation of that organ. If cardiac irregularity develops, manipulation is discontinued if possible until regular rhythm has been reestablished. In case of sudden cardiac arrest, epinephrine is injected into the right ventricle and cardiac massage is immediately started. Firm but not too strong

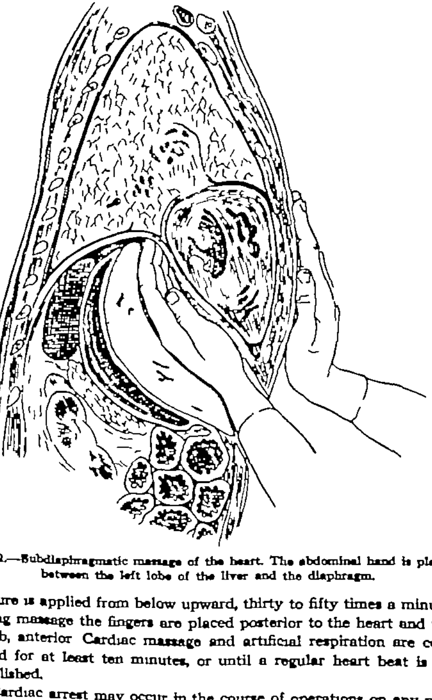


Fig. 22.—Subdiaphragmatic massage of the heart. The abdominal hand is placed between the left lobe of the liver and the diaphragm.

pressure is applied from below upward, thirty to fifty times a minute. During massage the fingers are placed posterior to the heart and the thumb, anterior Cardiac massage and artificial respiration are continued for at least ten minutes, or until a regular heart beat is reestablished.

Cardiac arrest may occur in the course of operations on any part

incision in the third or fourth interspace, extending from the sternum to the middle of the axilla (Fig 20) The adjacent cartilages are divided near the sternum for additional exposure After the pectoral muscles have been divided, the intercostal muscle is incised near the upper border of the fourth or fifth cartilage and a rib-spreading retractor is inserted and opened sufficiently to permit unhampered access to the heart. The anterior border of the left lung is retracted laterally and posteriorly to expose the mediastinal pleura overlying the pericardium (Fig. 21) The phrenic nerve is located as it courses downward on the pericardium and it receives an injection of 1 per cent solution of procaine. This nerve should be preserved The pericardium is incised perpendicularly, usually anterior to the phrenic

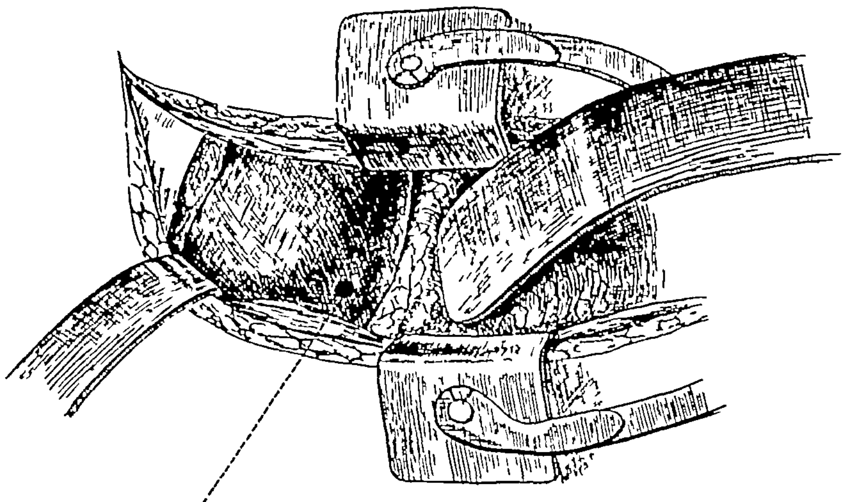


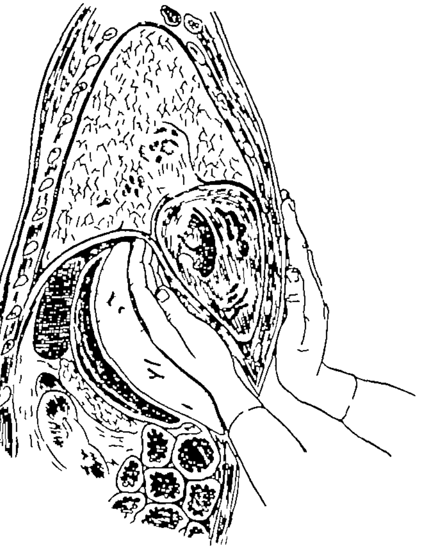
Fig 21—Transpleural exposure of a posterolateral bullet wound of the left ventricle

nerve, but the relation of the pericardial incision to the nerve depends on the location of the wound of the heart. Repair of this wound is carried out as described The pericardium is loosely approximated by interrupted sutures, so that serous fluid may drain from the pericardial into the pleural cavity, from which it can be removed by aspiration The incision in the thoracic wall is closed without drainage

CARDIAC ARREST

Cardiac arrest is particularly likely to occur in the course of operations on the pericardium or heart To prevent this, procaine solution (2 per cent) is dripped over the surface of the heart before,

and at frequent intervals in the course of, manipulation of that organ. If cardiac irregularity develops, manipulation is discontinued if possible until regular rhythm has been reestablished. In case of sudden cardiac arrest, epinephrine is injected into the right ventricle and cardiac massage is immediately started. Firm but not too strong



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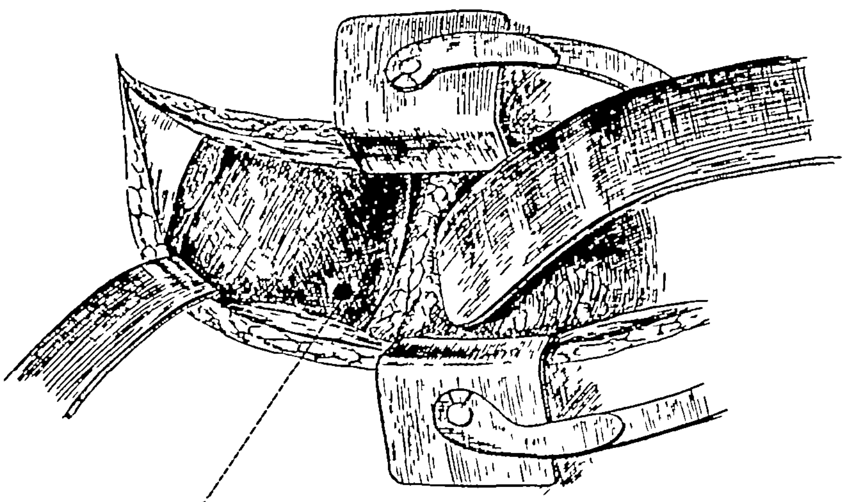

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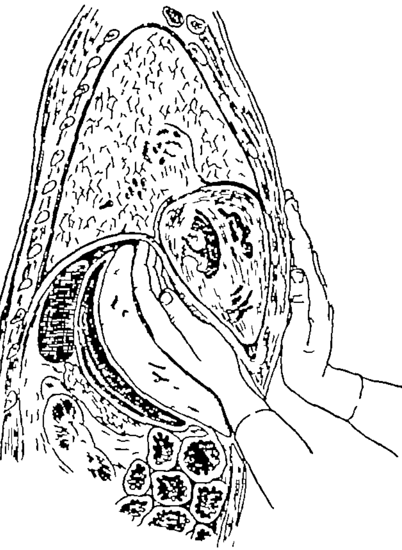

Fig. 22.—Subdiaphragmatic massage of the heart. The abdominal hand is placed between the left lobe of the liver and the diaphragm.

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Cardiac arrest may occur in the course of operations on any part

of the body, under either general or regional anesthesia Sudden cardiac arrest also may result from blows to the precordium or epigastrium It is essential that the heart be reactivated with as little loss of time as possible, for the brain does not withstand prolonged circulatory standstill From 5 to 10 minims of epinephrine (1 1000 solution) are injected into the cavity of the right ventricle and another 5 minims are injected into the wall of the ventricle The injection is made through a 22 gauge needle, 10 cm long, inserted in the fourth interspace, 1 to 2 cm to the left of the sternum The needle is passed in through the thoracic wall, the plunger is slightly withdrawn and the needle is passed directly backward, or very slightly to the right, until dark blood is obtained The first injection is made, the needle then is withdrawn, and when blood is no longer obtainable the second injection is made If response is not prompt, cardiac massage is instituted immediately If the abdomen or thorax is open, that route is used If neither cavity is open, the abdomen is rapidly entered through an upper left rectus incision, the surgeon's hand is passed upward beneath the diaphragm, and pressure is applied to the heart (through the diaphragm) from below upward and from behind forward (Fig 22) Simultaneous pressure is applied over the precordium The heart is thus compressed rhythmically about thirty to fifty times per minute and this is continued for at least ten minutes, or until the heart begins to beat spontaneously Artificial respiration with oxygen is given If an intratracheal tube is in place or is readily available, administration of oxygen under intermittent positive pressure is valuable However, care should be taken not to compress the breathing bag too strongly, as there is danger of rupturing the alveoli

PERICARDIOSTOMY

Drainage of the pericardium is best carried out through a curved incision extending along the sternal border, from the lower border of the third to the upper border of the sixth rib, then out along the sixth rib to the nipple line (Fig 23) The skin-fascia-muscle flap is turned up to expose the fourth and fifth costal cartilages, which are resected subperiosteally The intercostal bundles and periosteum are divided near the sternum and retracted to the left The internal mammary vessels are ligated proximally and distally and the loose prepericardial tissue is incised and stripped to the left with the pleura The pleura must not be injured After a sufficient portion of pericardium has been exposed, the pleura is protected by a gauze sheet and the pericardium is incised obliquely from above and medially, downward

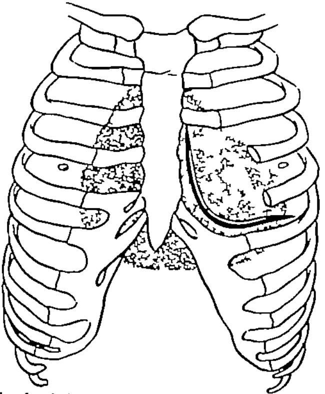

Fig. 23.—Incision for drainage of empyema of the pericardium. Note that the fused cartilages have not been resected.

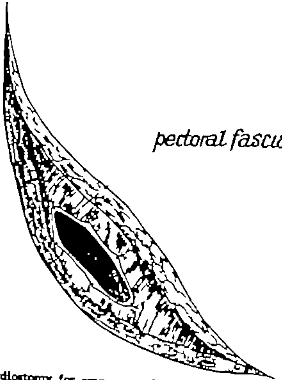

Fig. 24.—Pericardiostomy for empyema of the pericardium. The pericardium is sutured to the pectoral fascia. No drainage material is used.

and laterally. The incision in the pericardium is 5 to 6 cm long and is made with great care to avoid injury to the heart, which may be adherent anteriorly Pus is removed by suction and adhesions between the pericardium and epicardium are gently separated by directing the pressure of the palmar surface of the fingers against the inner surface of the pericardium The edges of the pericardium are sutured to the pectoral fascia, not to the skin (Fig. 24) Drainage material is not inserted Postoperatively, fresh adhesions must be separated by the sterile, gloved index finger at least once in each twenty-four hours for several days, otherwise pus may become walled off posterior to the heart

SUPRASTERNAL COLLAR INCISION FOR MEDIASTINAL EMPHYSEMA AND WOUNDS OF THE TRACHEA

It should be remembered that there is danger of air embolism if any of the large veins of the neck are opened, especially when there

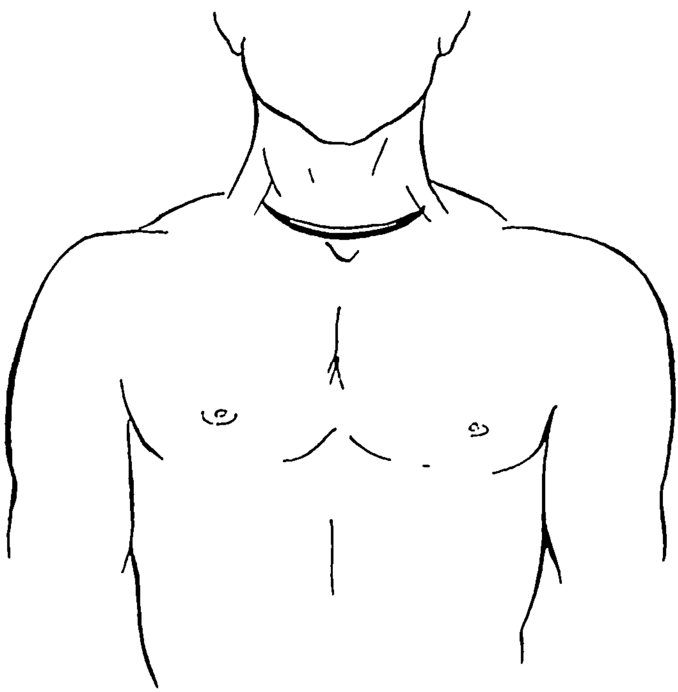

Fig 25—Incision for suprasternal mediastinotomy

is inspiratory difficulty Conversely, these veins are likely to bleed profusely when there is expiratory difficulty

In the presence of wounds of the trachea, or of mediastinal emphysema from other causes, a suprasternal incision may be life-sav-

ing. Under procaine infiltration, a transverse incision about 8 to 10 cm. long is made just above the sternum (Fig. 25) The skin and platysma muscle are divided and, while pressure is applied below to distend the veins, they are doubly ligated and severed between the ligatures. The ribbon muscles of the neck are separated (Fig. 26) by a vertical incision in the midline and, if necessary for adequate

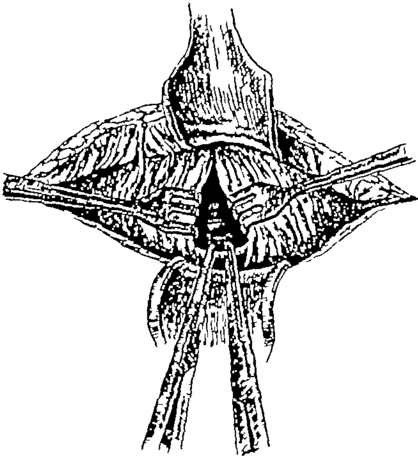

Fig. 26.—Suprasternal mediastinotomy for relief of mediastinal emphysema. The anterior jugular arch has been clamped on each side of the midline. The ribbon muscles are being retracted laterally but may be divided transversely if necessary for adequate exposure. Low tracheotomy also may be performed through a similar incision.

exposure, are divided transversely In separating the lower portion of these muscles, large veins must be carefully ligated and divided. The trachea is exposed below the thyroid isthmus by blunt dissection. If a tracheal wound is found it is closed by suture if possible Otherwise a tracheotomy tube is inserted. The skin and muscles must not be sutured.

TRACHEOTOMY

For low tracheotomy a vertical incision 5 cm long is made just above the sternum The ribbon muscles are separated by an incision and retracted laterally Large veins cross the midline and are caught and severed between ligatures The thyroid isthmus is retracted upward A vertical incision is made in the midline of the trachea, cutting across one or two cartilaginous rings The tracheal edges are separated by small, sharp-clawed retractors and a tracheal cannula is inserted The tissues superficial to the trachea are left open. If there is great urgency tracheotomy may be performed by a single stab wound into the trachea

THORACO-ABDOMINAL INJURIES: REPAIR OF LACERATION OF DIAPHRAGM (TRAUMATIC DIAPHRAGMATIC HERNIA)

This is usually not an emergency operation unless the injury is compounded Vomiting, pain, shock and distention—the signs of intestinal obstruction—may be present. Not infrequently these patients are operated on under a tentative diagnosis of ruptured abdominal viscus. If the correct diagnosis is made, access can be gained either transpleurally or transperitoneally The transpleural route has the advantage of immediately equalizing the pressure in the thoracic and abdominal cavities and thus making reduction of the prolapsed abdominal viscera easier It also permits access to the phrenic nerve, which courses along the pericardium Repair of the diaphragm is facilitated if this nerve is temporarily paralyzed by lightly crushing it with a hemostat. The transpleural approach allows intrathoracic adhesions between the prolapsed viscera and the lung to be divided under direct vision Since in late cases adhesions are often dense and troublesome, the thoracic approach is the one of choice when the injury is of more than a few weeks' standing

The abdominal route offers a satisfactory approach for early cases without dense adhesions, and is quicker and easier for surgeons who are more accustomed to work in the abdomen than in the chest. Intratracheal differential pressure anesthesia is advisable in either case

Transthoracic Approach

A Levin tube is passed into the stomach before anesthesia is induced.

External wounds are excised deeper structures are sutured to close the pleura or peritoneum and the wounds are packed open, with local application of a sulfonamide.

For the major incision, resection of the ninth or tenth rib is performed from the transverse process of the vertebra to the anterior axillary line. The pleura is incised through the periosteal bed of the resected rib and the incision is spread widely with the mechanical retractor

If the injury has been a penetrating wound, careful inspection of viscera is made for perforations. The rent in the diaphragm may be enlarged for further exploration of viscera that lie in the abdominal cavity Exploration is aided by deflation of the stomach by means of the Levin tube. When bleeding vessels have been secured and perforated viscera repaired, the abdominal organs are reduced through the opening in the diaphragm.

The edges of the laceration in the diaphragm are excised and approximated by interrupted sutures. If an actual defect has been created by tearing away of the diaphragm from the thoracic wall, it is closed by reattachment at a higher level.

Lung that was atelectatic on opening the chest should not be forcibly reinflated, but otherwise the lung is reexpanded during closure of the incision.

On the right side, the liver may be injured by the missile. If a pack is required it is brought through the lateral wall of the abdomen and the diaphragm is closed above it.

The indications for drainage are the same as those discussed under thoracotomy (p. 280)

Abdominal Approach

If a median laparotomy is made under the diagnosis of ruptured viscus, the incision is prolonged to the xiphoid process if the correct diagnosis is made, a left paramedian incision from the xiphoid process to the umbilicus gives the best exposure. If exposure is inadequate, more room can be gained by cutting the left rectus muscle across at one of the transverse lines. Incision of the rib cartilages will rarely be necessary Division of the coronary ligament of the liver and retraction of the left lobe of the liver to the right, will improve the exposure of the under surface of the diaphragm. Downward traction on the stomach usually will deliver it and the colon will follow the stomach. By holding the viscera down and to the right with a large laparotomy sponge held in the open left hand, the diaphragm will be visualized. The edges of the laceration are then united with inter

rupted sutures. By leaving each successive suture long and making traction on it, closure of the opening is facilitated.

MEDIASTINOTOMY

Early wounds of the esophagus are exposed for repair either by a cervical incision or by transpleural thoracotomy, depending on the level of the injury

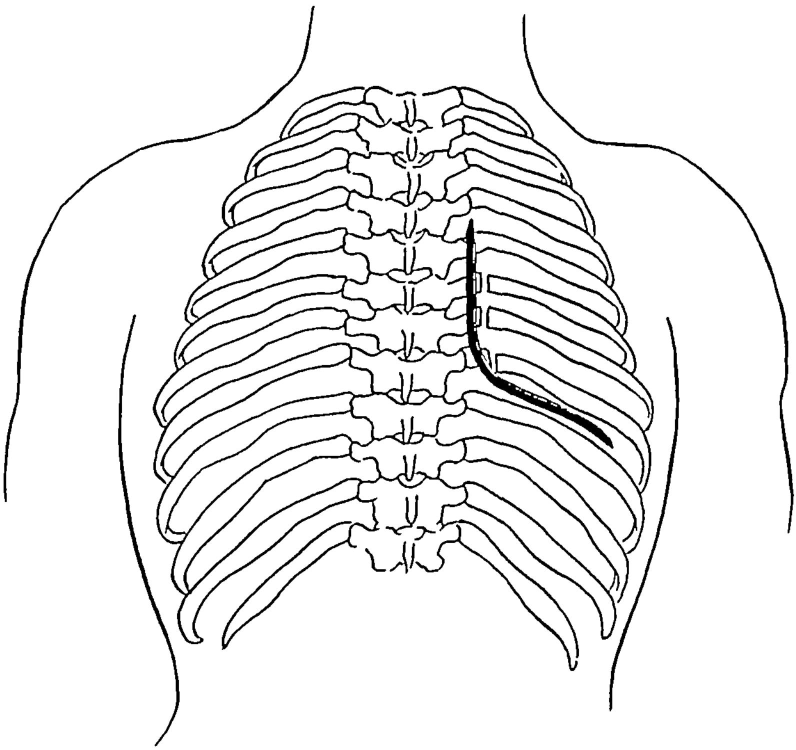

Fig 27—Incision for extrapleural exposure of the esophagus (posterior mediastinotomy) When the posterior mediastinum is being explored for pus, the horizontal arm of the incision is unnecessary and the resection of longer segments, 6 or 7 cm, of only one or two ribs gives adequate exposure The level of the esophageal perforation or of the region of infection determines the level of the incision

A recent laceration of the esophagus is closed with interrupted silk sutures, with precise approximation of the mucosa The muscular coat is so friable that the safety of the suture line depends on mucosal healing

A nasal tube is passed into the stomach while a finger in the incision can guide it past the region of injury Penrose drains are inserted, but not in contact with the region of repair

Infection develops rapidly and, for late cases or for drainage of

a mediastinal abscess when there is no evidence of a communication with either pleural cavity an extrapleural approach is desirable. This may be cervical or posterior

Cervical Mediastinotomy

This is employed for perforation of the cervical or upper thoracic portion of the esophagus, or for drainage of a superior mediastinal abscess (above the level of the sixth thoracic vertebra)

An oblique incision is made along the anterior border of the sternocleidomastoid muscle The carotid sheath is retracted laterally

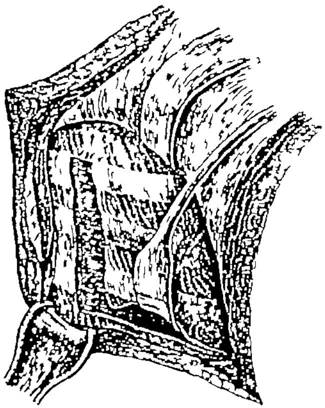

Fig. 28.—Posterior mediastinotomy Resection of short segments of three ribs preliminary to separation of the pleura from the vertebrae. The transverse processes and the heads of the ribs may be removed to shorten the distance into the posterior mediastinum.

after ligation and division of the lateral thyroid vein. If the inferior thyroid artery is exposed, it can be retracted upward or doubly ligated and divided. When the prevertebral fascia is reached, the upper part of the posterior mediastinum can be entered by carrying the dissection downward on this plane. If drainage of an abscess is

required, a soft rubber tube is sutured in place and drainage by gravity is facilitated by raising the foot of the bed

Posterior Mediastinotomy (Extrapleural)

For exposure of the esophagus, at least three and at times four ribs are divided posteriorly, the level depending on the level of perforation The lower end of the incision is curved laterally, extending

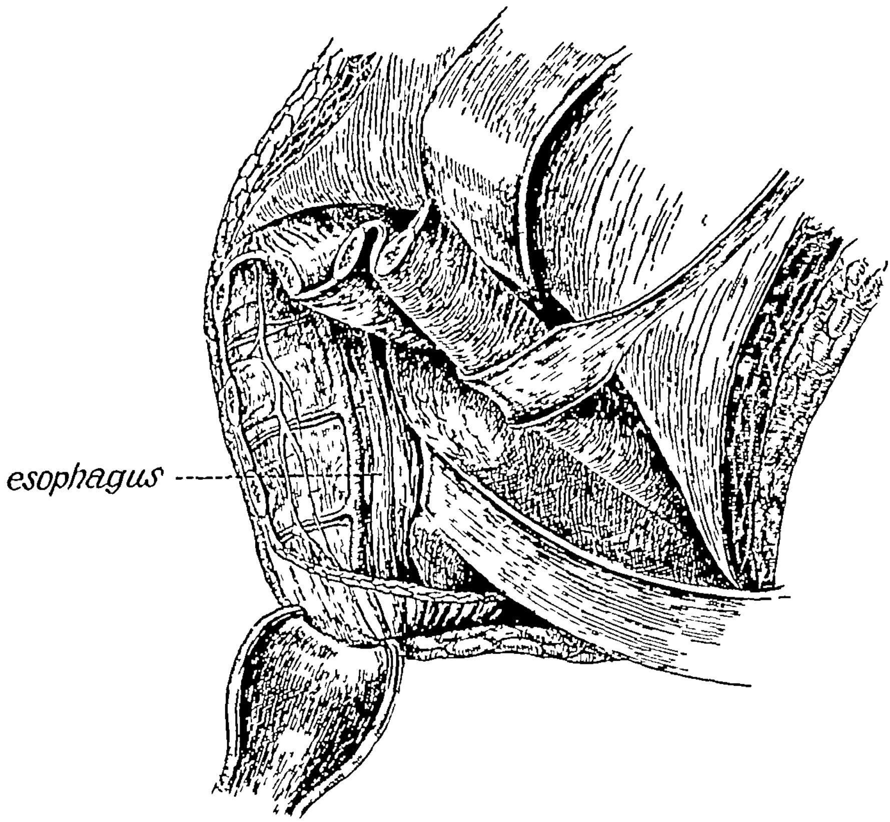

Fig 29—Posterior mediastinotomy An intercostal incision added to the lower end of the perpendicular incision gives a more adequate exposure The pleura must be freed up well above and below the horizontal arm of the incision so that it will not be torn when the ribs are widely separated Excellent exposure of the esophagus can be obtained in this way

10 cm along the lowest rib to be resected (Fig 27) The sacrospinalis muscle is retracted toward the spinous processes of the vertebrae and short segments are removed from the ribs between their angles and the transverse processes of the vertebrae (Fig 28) The pleura is separated from the overlying ribs for a sufficient distance laterally, and above and below, to avoid tearing when the ribs are retracted. At least two intercostal bundles are divided between liga-

tures to provide adequate exposure. The pleura is then carefully separated from the vertebral bodies until the esophagus is reached (Fig. 29)

To Establish Drainage of an Abscess or to Exteriorize a Region of Mediastinitis Surrounding a Perforation.—The utmost care must be taken to avoid opening the pleura. Under local anesthesia, an incision 12 cm. long is made parallel to the border of the sacrospinalis muscle, centering over the rib or ribs to be resected. The latissimus dorsi is divided and the erector spinae muscles are mobilized by severing their tendinous attachments to the ribs. The transverse processes of two vertebrae are exposed and the articulations

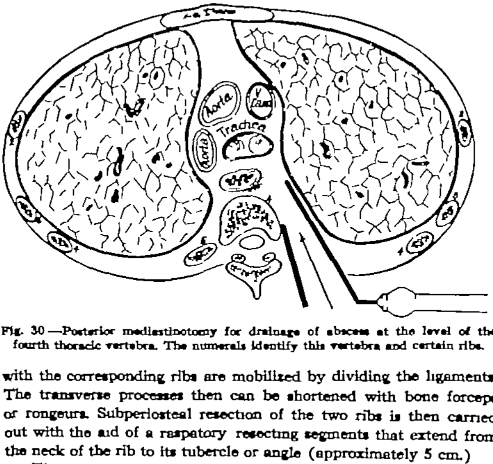

Fig. 30—Posterior mediastinotomy for drainage of abscess at the level of the fourth thoracic vertebra. The numerals identify this vertebra and certain ribs.

with the corresponding ribs are mobilized by dividing the ligaments. The transverse processes then can be shortened with bone forceps or rongeurs. Subperiosteal resection of the two ribs is then carried out with the aid of a raspatory resecting segments that extend from the neck of the rib to its tubercle or angle (approximately 5 cm.)

The posterior periosteum is carefully divided and the intercostal vessels are divided between double ligatures. Intercostal nerves are severed with a sharp knife or retracted (Fig. 30)

The pleura is gently separated from the vertebral bodies suspensory ligamentous attachments are divided by sharp dissection to avoid tearing. Access is thus gained to the posterior mediastinum and,

required, a soft rubber tube is sutured in place and drainage by gravity is facilitated by raising the foot of the bed

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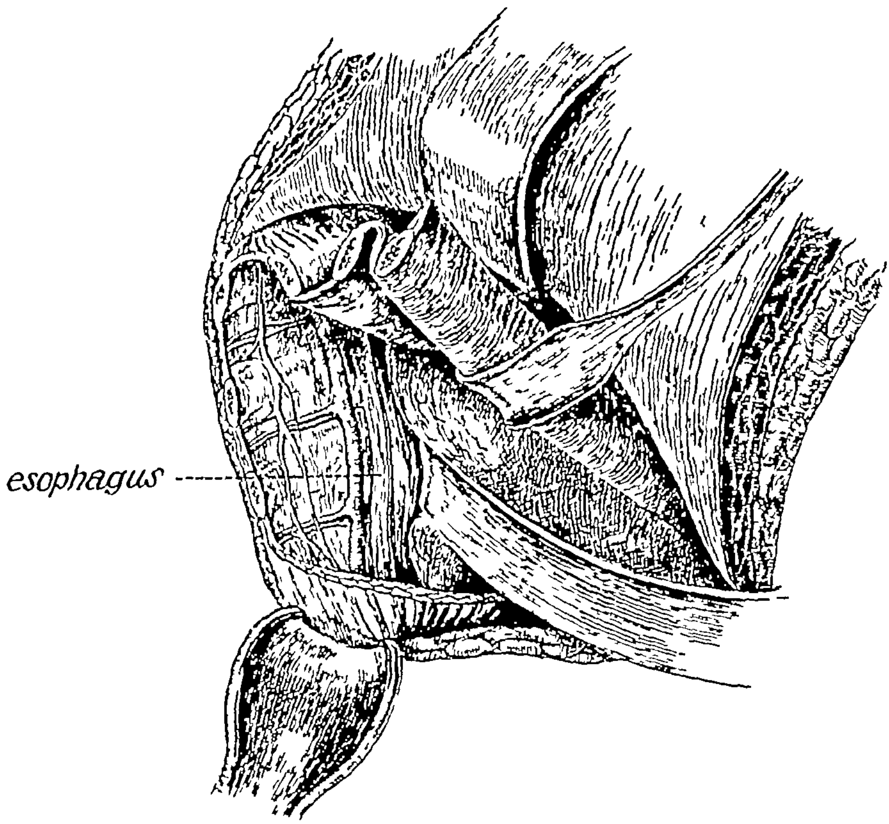

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if pus is present, it is reached at the level of the esophagus Penrose drains are inserted and the incision is packed lightly with gauze

This approach is used on the right side down to the level of the eighth thoracic vertebra The azygos vein crosses the field at the level of the fourth thoracic vertebra Below the eighth thoracic vertebra, a left sided approach is employed. The aorta, as it descends, lies lateral and posterior to the esophagus

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